Spatial Distribution of Urban Territories at a Regional Scale: Modeling the Changjiang Delta's Urban Network

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A dissertation presented

by

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Abstract

The formation of 'Urban Networks' has become a wide-spread phenomenon around the world. In the study of metropolitan regions, there are competing or diverging views about management and control of environmental and land-use factors. Especially in China, these matters, regulatory aspects, infrastructure applications, and resource allocations, are important due to population concentrations and the overlapping of urban areas with other land resources. On the other hand, the increasing sophistication of models operating on iterative computational power and widely-available spatial information and techniques make it possible to investigate the spatial distribution of urban territories at a regional scale.

This thesis applies a Scenario Cellular Automata (SCA) model to the case study of the Changjiang Delta Region, which produces useful and predictive scenario-based projections within the region, using quantitative methods and baseline conditions that address issues of regional urban development. The contribution of the research includes the improvement of computer simulation of urban growth, the application of urban form and other indices to evaluate complex urban conditions, and a heightened understanding of the performance of an urban network in the Changjiang Delta Region composed of big, medium, and small-sized cities and towns.

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Chapter 1: Introduction

This thesis is about urban formation and predicted growth at a metropolitan regional scale and assessment of its implications for further sustainable development. The region in question is the Changjiang Delta area of China and the metropolitan areas of Shanghai, Hangzhou, Suzhou and Nanjing, among others, or, more broadly, a conglomeration of numerous large, mid-sized and small cities and towns. The period of interest is largely from China's historic opening to the outside world in 1978 extending to 2030 or thereabouts, and the time at which the present rise in urbanization will become more stabilized and natural population begins to decline. Measures of sustainability at work in the investigation embrace environmental conditions and performances, economic development and potential well-being, and the influence of cultural contributions including their maintenance. In almost all regards empirical data is deployed with an emphasis on spatial distribution, and empirically-driven models and conceptual formulations are both appropriated and devised to both predict future urban growth and change, as well as to assess its likely consequences. In this last regard, pursuit of empirical results is directed towards broad and relevant questions of policy interest in regional management, even though the principal contributions of the research are rather more technical and concerned with representation, prediction and analyses in a world of variable and imperfect information.

1. Metropolitan regional management and controls.

In both the study and management of metropolitan regions there are competing and different views about the influence of environmental, economic and cultural factors, particularly with regard to urban settlement and land use. Among these, at least three broad categories emerge and stand out. The first involves regulation, typically of the spread and composition of urbanization within a host environment (Munizzo & Musial, 2010; Spool, 2014). Sometimes this is done with regard to perceptions of rightness of scale, i.e., the encouragement of smaller-scale settlements at the expense of larger ones, for instance. At other times it is pursued with regard to limits on the extent of urban or land-use characteristics, such as buildable area ratios and the like. The second category involves the use of infrastructure as a guiding hand in development. It is well known, for instance, that a doctrine of highest and best use often follows or correlates highly with spatial proximities and accessibilities (Turner et al., 2014; Fischel, 2015). The presence or absence of vital resources, such as water and energy, not to mention flood control and other aspects of natural disaster mitigation, are strongly infrastructural with regard to urban development and such dependencies can be used to guide urban growth and change. A third category concerns balancing resource allocations and scales of development into virtuous arrangements with respect to production, environmental consumption, and socially equitable outcomes (Mills, 1967; Goulias, 2007). This may well involve both regulation and infrastructural guidance, but also fundamentally uses economic and social incentives to achieve results. Here, lending practices and different levels of investment have formed stimulants favoring certain outcomes over others.

2. China's regional urban growth and management.

China's regional urban growth, particularly in places like the Changjiang Delta, has contributed to a rise from under twenty percent of the total population living in urban circumstances around the time of the opening up in 1978, to slightly over 50 percent today. Remarkable though this transition may be in sheer magnitude of numbers, it took place generally under a gradualist approach without excessively high rates of change and with different broad strategies in place at different times. It began with large cities, like Shanghai, remaining constrained in development against encouragement of smaller cities, towns and rural settlements. Commodification of urban activities, such as housing, was also pursued relatively aggressively, shifting urbanization into a more thoroughly marketized phenomenon. Responses to excessive duplication and fragmentation of economic activity, among other causes, were then pursued, including liberalization of larger cities and other places with comparative advantages. More recently, this normalization of urbanization into relatively conventional pathways forward has been augmented by a new townization policy, which now places strong emphasis on community and life-style services and amenities in lower-tier cities and towns in order to stimulate domestic consumption, stabilize intra-urban migration, and improve the quality of life of citizens. One of the other broad strategies in play, at least implicitly, is also a version of a 'third way' in spatial urban formation, whereby China takes advantage of its inherently bi-polar distribution of urban population among large and mid-sized cities versus smaller towns in order to secure a better future with regard to environmental and social qualities of life[1]. This is particularly apparent, at least potentially, in the Changjiang Delta, already the home to some 70 million inhabitants. It is also of high relevance to this study and the selection, development and deployment of empirical techniques with emphases on different scales of development, networking arrangements, infrastructure alignments, and relatively few background assumptions about future growth directions, results and outcomes.

3. Organization of the thesis

[1] 'Third ways' with regard to community, urban, and national developments have various construals. In broad political terms proponents have sought to merge social and community concerns with market-driven revitalization as a reaction to top-down control or rampant bottom-up market machinations. In competitions between various resource classes such as 'urban' versus 'agriculture', third way solutions emphasize radical changes in one or other side of the balance. Third way, as used here, refers to well-networked clusters of developments at a variety of inter-mixed scales in place of a. predominantly large cities, or b. loose aggregations of relatively numerous smaller-scale settlements.

The thesis is comprised of six chapters. Chapter 1 is a general introduction. Chapter 2 investigates how to define a regional scale appropriately. It starts with a brief background of regional urban networks worldwide, leading to a discussion of China's regional urban networks. The chapter then concludes with aspects of concern which define the terms of regional urban networks. Chapter 3 discusses the salient characteristics of the Changjiang Delta Region. This chapter briefly discusses the historical development of the Changjiang Delta Region, which is placed in a national context to exhibit the leadership role of regional urban cluster development. Building upon this, the chapter further discusses the boundary changes of the Changjiang Delta and the implications of regional expansion. Then, the present state of Changjiang Delta regional network is described as a structure of big, medium, and small-sized cities and towns. Chapter 4 assesses different modeling approaches for potential future urban development patterns. Of the alternative models, Cellular Automata, a land-based model using algorithmic processes, appears to be the most appropriate for this kind of investigation. Then the generic Cellular Automata model is modified to address specific scenario conditions. The then modified Scenario Cellular Automata model is applied to four selected scenarios to project future urbanization patterns within the Changjiang Delta region from 2011 to 2030. The predicted outcomes are compared with three baseline measurements: environmental suitability, economic performance, and cultural amenity. The comparison reveals the impacts of future urbanization patterns on these three baselines. The applications and contributions of the research are then discussed. Chapter 5 revisits the history and formation of regional urban networks. It is followed by the reinstatement of the findings and results of the research. Chapter 6 reexamines the contributions of the research and discusses the future opportunity for further investigation and the implications for further research.

Chapter 2. Defining a regional scale appropriately

This chapter introduces the background of regional urban networks briefly. The first part reviews the concept of a regional urban network ranging from the early twentieth century and Chicago's regional urban planning to the more recent metropolitan developments centered on employment. The second part of the chapter examines the conventional Chinese wisdom of the regional concept, which also relates to the philosophy of contemporary China's urban network development. Finally, discussion centers on spatial and functional units replacing traditional core and periphery models of regional urban networks.

1. Brief background of a regional urban network

The concept of a regional urban network is not a modern invention. Urban areas are palpably connected by physical links, such as roads, railways, and canals, and immaterial links such as trade, finance, and culture. These links weave out a network of multitudinous elements. Within an urban network some linkages are stronger than others, and some linkages are more interrelated to others. However, until the early twentieth century, studies of urbanization have focused on single city cores and their peripheries using the core and periphery model. They emphasized the city center and the suburban area and the connectivity in between (Scott, 2000). In the 1910s, Chicago's urban planning started to contain regional factors such as regional transportation and open space provision. Two rival traditions of planning theories, one called 'metropolitanist' and the other 'regionalist', reached their heights in the 1920s (Fishman, 2000). Ultimately, both failed to properly address regional planning issues. American planning was pushed to a low ebb by the 1960s (Fishman, 2000). In the 1940s, spatial planning flourished as a result of post-war reconstruction of many European countries (Fishman, 2000). Central place theory, location theory, and growth pole theory were all developed during the time period. In the 1950s, quantitatively-based research challenged the traditional regional geographic studies. 'New Regionalism' emerged after World War Two in the form of Jean Gottmann's 'Megalopolis' (Hack, 2001). In the 1980s, mainstream social science started to recognize 'regions' as basic organizational units. According to one recent account they were "one of the most advanced organizational forms for coordinating capitalist social and economic life and a crucial source of competitive advantage" (Lu & Fan, 2010). In one construal, an urban employment area was defined by Kanemoto and Tokuoka (2002) as an area with a core of a densely inhabited district and an outlying municipality where employed workers resided. The urban employment area was a large urban employment area with at least 50,000 people. The number was arbitrary and varied in different countries. For example, in the Chinese case the threshold might be substantially larger than the Metropolitan Employment Area depending on the prevailing circumstances.

2. Regional urban networks in China

Ancient Chinese used Feng-Shui to choose the sites for settlements. They kept the balance of Yin and Yang (dark and bright) to harmonize the flow of 'Qi', which considered man, state, nature, and heaven. The principle of Feng-Shui was comparable to a multi-disciplinary study nowadays that incorporates consideration of population, economics, and the environment (Zhang, 2012). Both the Yellow River Delta and Changjiang Delta were urbanized under such classical standards in antiquity. However, most scholars of China's regionalization have concentrated on the period after 1978 (Hall, 2000). By contrast, in the U.S. and in European countries, modern urban and regional planning practice and theory can be traced back to the end of nineteenth century. While listing some significant events chronologically of the western world parallel to China gives us a sense of how Chinese regional urban networks fit into the global stage of development, the Chinese case has its own exceptional qualities with regard to the timing and scale of development.

In the twenty-first century, as a consequence of globalization, new technology involving information and transportation pushed the study of urban circumstances to a metropolitan area and an urban employment area and to a larger scale --- the regional urban cluster. Indeed, regional urban clustering appears to be a global phenomenon (Sorensen, 2011). Its formation often goes beyond national boundaries, such as the so called 'Blue Banana' extended from England to Italy in European Union countries. Others were developed within nations by amalgamating cities cross the administrative boundaries, such as Changjiang Delta. More and more people live in regional urban cluster areas now. By 2007, megacity populations (more than 10 million) accounted for nine percentage of the world population and the number is predicted to increase dramatically in developing countries (UNDESA, 2008). No doubt the transformation of human settlement will reshape the future of human civilization (Sorensen, 2011).

In China fifty percent of the populations now are living in cities. This number will probably rise to seventy percent when the urbanization process stabilizes probably by mid-century. Among the urban dwellers, an increasing number of urbanites now live in city regions which form an even larger regional urban network. Presently in China, substantial urbanization has taken place at two ends of the scale spectrum: in large cities, of which there are roughly 120 greater than one million in population, and among smaller towns of which there are thousands (China Statistical Yearbook, 2015). Consequently, the regional urban network in China is and will continue to be populated by small, medium, and large scale settlements. Also, the relational characteristics of the network seem likely to affect performatory aspects, such as ecological footprints and economic growth.

3. Defining a regional urban network

In this research a regional urban network will be the basic spatial and functional unit, replacing the core and periphery model of the traditional city. This network of human settlement will include social, economic, as well as political aspects. They will be conceptualized and expressed in the form of relational complexes or sub-networks among spatial locations. The overall extent of the regional urban network – in the case of the Changjiang Delta region – will be defined by the points in the spatial coverage when and where the links in the networks are substantially diminished in the strength. Of course at some abstract level all locations in the potential network maybe regarded as being connected to the others. However, at an operational or practical level, these linkages are stronger or weaker than others, suggesting limits to the regional operation of a network and, therefore, the range of the spatial domain. Network analysis tools, such as those used in relationship to 'twitter constellations', can be deployed as aids in this definition.

Chapter 3. The salient characteristics of the Changjiang Delta Region

This chapter briefly discusses the historical development of the Changjiang Delta Region, which is placed in a national context to exhibit the leadership role of regional urban cluster development. Built upon this understanding, the chapter further discusses the boundary changes of the Changjiang Delta and the implications of regional expansion. Then the present state of the Changjiang Delta regional network is described as a structure of big, medium, and small-sized cities and towns, including salient boundary characteristics.

1. Brief historical development of the Changjiang Delta region

At this juncture, together with the Pearl River Delta and the Bohai Rim, the Changjiang Delta is one of the three most urbanized regions in China. In fact, its regional urban structure is more mature than most others in China. For example, the Bohai Rim which is still yet to become a true regional urban cluster is less mature. As such the Changjiang Delta is a good point of departure to examine future aspects of urbanization in China. Additionally, the economic capacity of the Changjiang Delta is extensive, much larger than the Pearl River Delta and the Bohai Rim. Even though the Bohai Rim might have great potential for further development from geographic and population points of view, the region must first surmount numerous difficulties, including a lack of natural resources like water.

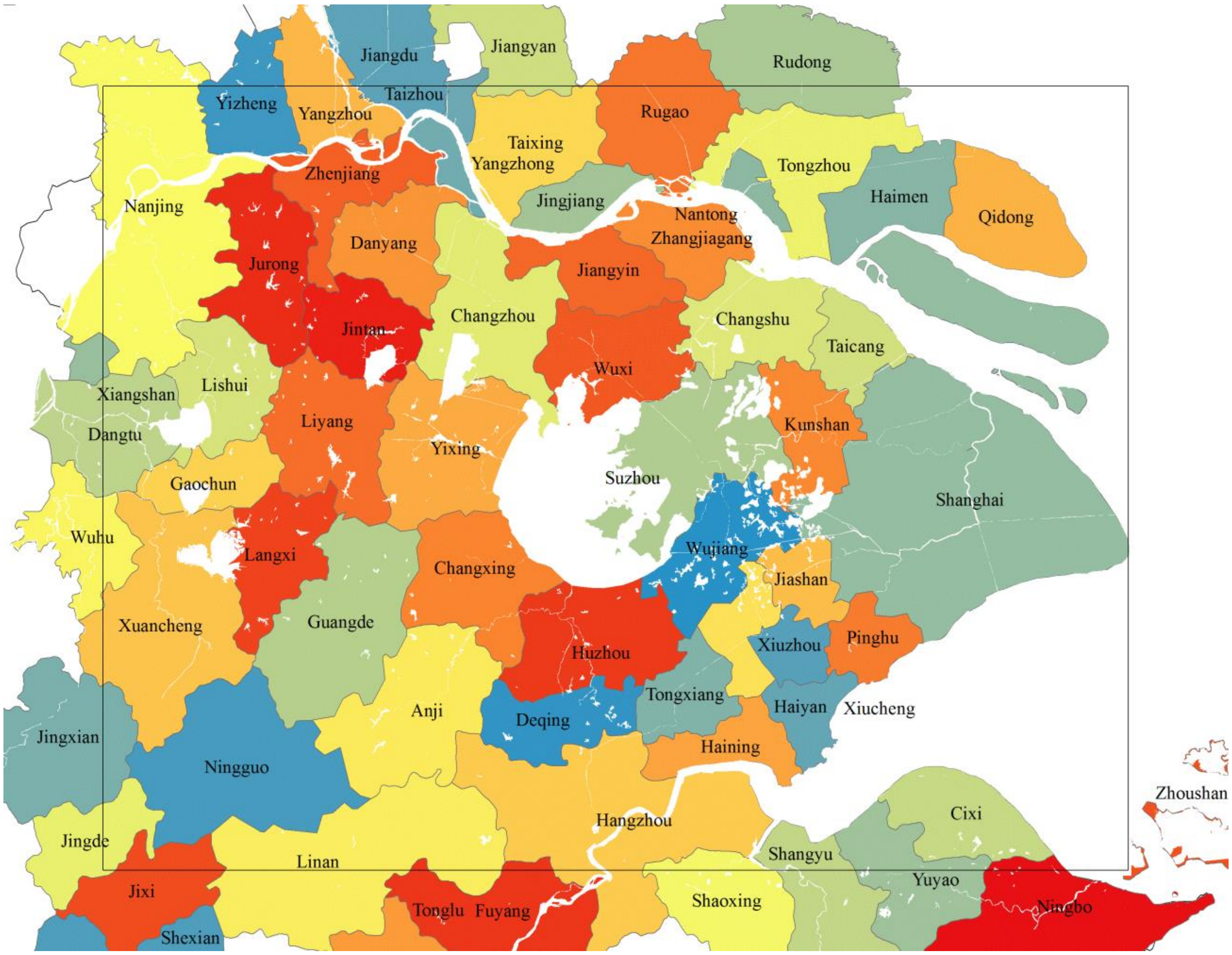

Figure 1. Major cities in the Changjiang Delta region in 2010 and boundary definition of the region. Source: Drawn by Author based on the GIS database, ArcMap, Gis /Automata_sh / boundary, administrative/county boundary.

Prior to the 1840s, the Changjiang Delta was an urbanized region. Yangzhou, Hangzhou, and Nanjing were the primary cities in the region. In addition to these cities, it was also populated by a dense pack of smaller towns and villages with a strong agricultural economy. Between 1840 and 1949, with the rise of Shanghai handling more than sixty-five percent of the national exports and imports, the delta region became a material distribution center by connecting sea trade with the Changjiang waterway transportation system (Keller et al., 2011). It was also the period during which both development in industry and the service sector flourished in Shanghai, making it one of the largest cities in the world. Then, from 1949 to 1978, a regime of highly-controlled urban development and a linear, rigidly hierarchical administration system was established. Some market towns lost their critical positions as circulation centers for agricultural products under a national uniform purchase policy. However, construction of basic agricultural infrastructure and communal industries laid the ground work for future local economic prosperity and in situ urbanization (Zhu, 2006). Chen and Sun, among others, even suggested that the city-town hierarchical system was becoming flat (Chen et al, 2007). With the historical opening up to the outside world in 1978, the Delta region then went through processes of controlled development of larger cities like Shanghai, coupled with encouraged development of smaller settlements. This began to change in the mid-to-late 1990s, with pursuit of more conventional urban pathways forward, and the substantial rise of Shanghai, in particular, as an international city. Today it dominates regional development, but not without a vast network quality to it, as well.

2. Defining a boundary for the Changjiang Delta

Shanghai, the largest city in the Changjiang Delta region in terms of economic activities and international influences in the 21st century, is the dragon head of the region. Consequently, some researchers use the Shanghai Municipality, Jiangsu Province and Zhejiang Province as a study area. It is suitable for provincial level research. However, this definition is too ambiguous and arbitrary for the research on Changjiang Delta Regional Urban System: The cultural barriers between the alluvial plains and mountainous regions are substantial, for example, Wenzhounese typically will identify themselves as an independent group by language, education, and clan relationship. The economic dissimilarities are also extensive. The ‘Subei’ region, which is far north of the Changjiang, represented by Xuzhou among other cities is developed much slower than the southern counterpart.

The definition of Changjiang Delta region boundary is not stagnant but has fluctuated throughout history. However, its boundary has both spatial and temporal dimensions. The formation of the ‘Changjiang Delta Consortium’ and the annual Mayors conference is a convenient vantage point to review the growth process since 1993. What follows is a snapshot of the membership from 1996 to 2013:

15 Cities---1996: Changzhou, Hangzhou, Huzhou, Jiaxing, Nanjing, Nantong, Ningbo, Shanghai, Shaoxing, Suzhou, Taizhou, Wuxi, Yangzhou, Zhenjiang, and Zhoushan

16 Cities---2003: Taizhou

22 Cities---2010: Hefei, Huaian, Jinhua, Ma’anshan, Quzhou, and Yancheng

30 Cities---2013: Chuzhou, Huainan, Lianyungang, Lishui, Suqian, Xuzhou, Wenzhou, and Wuhu

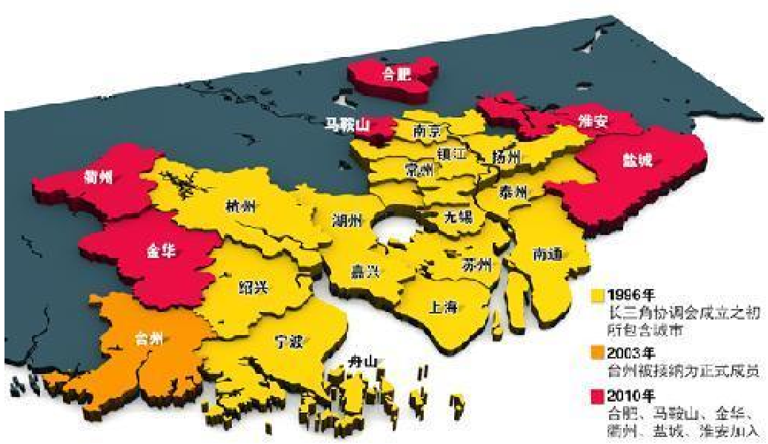

Figure 2. The evolution of the Changjiang Delta Consortium, 1996 to 2010.
Source: Dongfang Daily, March 26th, 2010. In Chinese:长三角协调会首纳安徽两城增至 22 个
http://finance.ifeng.com/news/20100326/1964963.shtml

Figure 3. The evolution of the Changjiang Delta Consortium, 2013.
Source: Dongfang Daily, April 15th, 2013. In Chinese: 长三角将联合应对公共事件
http://roll.sohu.com/20130415/n372702222.shtml
http://www.dfdaily.com/html/8730/2013/4/15/978765.shtml

Economies of scale create huge development opportunities for the membership cities. Every city wants to be part of the Changjiang Delta Consortium, by joining the annual 'Changjiang Delta Mayors Conference' (Dongfang Daily, 2010). At the current stage, however, not all 30 cities should be considered part of the regional urban system. The growth of the consortium is faster than the actual growth of the region. Wenzhou, for example, is historically developed from a very different economic and cultural background. Geographically, it is appropriate to consider Wenzhou as an external element interacting with Changjiang Delta Region as a whole, rather than as an internal component of the system. It will take Wenzhou a long time to truly be part of the Changjiang Delta Regional Urban System, if it happens at all.

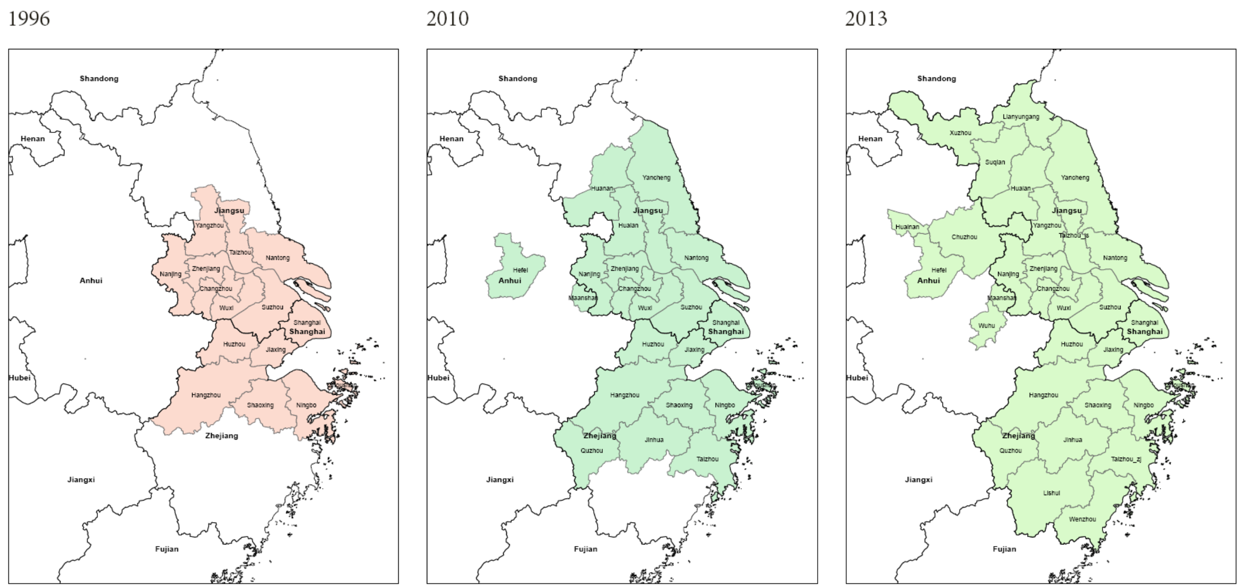

Figure 4. The spatial distribution of the Changjiang Delta Consortium 1996, 2010, and 2013.
Source: Drawn by author based on the conference memorandum of the Changjiang Delta Consortium.

3. Present state: a structure of big, medium, and small-sized cities and towns

Among others, Marton explores the nature of the spatial economic restructuring in the lower Changjiang Delta. Instead of the core city expanding, many cities in Changjiang Delta show a reverse pattern. County level cities have developed faster than peripheral areas of large cities. Interpretation can be made in two ways: one is the multiple core of the urban employment area, the large city being the central core and the smaller county level cities being the multiple cores; the other is a deviation from the typical Urban Employment Area model. The central city is developed because of the peripheral urbanization. In both scenarios, the results revealed that the regional differences widened (Marton, 2000). In the 1990s, an emerging pattern showed a lack of development in the adjacent area of Shanghai and Nanjing but relatively higher industrial production and urbanization in the country side (Marton, 2000). The industrial development also coincided with high agricultural productivity. This supports a multi-centered regional urban formation. Zhang (2000) has suggested four types regional space structure model: V-shape, N-shape, and W-shape. Essentially, these are morphological shapes formed by nodes and links. The V-shape described an area expands from Nanjing to Shanghai and then to Hangzhou, forming a geometry resembles the letter V. The N-shape extended the area from Hangzhou to Ningbo, hence the name N. The W-shape further stretched the region from Ningbo to Wenzhou, a city which lacks topographical as well as cultural similarities with the rest of the region.

Presently, the Changjiang Delta region, with the boundaries more or less specified by this discussion, is inhabited by urban settlements of a variety of scales and population sizes, as noted earlier. Partly as a legacy of the past and deeply entrenched agricultural practices, there are numerous small town and village settlements, dispersed fairly evenly within the fertile plain of the delta. In addition, there are larger towns, many on their way to coveted definition as cities. Then there are cities, dominated by Shanghai with a total settlement population in excess of 20 million inhabitants, followed by Hangzhou, Suzhou, Wuxi, Changzhou and Nanjing, to have but a few of the relatively large cities in the region. Infrastructural development has also proceeded apace with development, including high-speed rail links among the mega-urban areas such as Ning-Hang High-speed Railway[2]. Figure 5 shows the study boundary of a similar research of the

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[2] China High-speed Rail, Gaotie (2015) The Nanjing-Hangzhou Passenger Railway (宁杭高铁) is a high-speed rail (maximum speed 350 km/h), passenger-dedicated line in eastern China between Nanjing (shorthand name Ning) and Hangzhou, the capitals of Jiangsu and Zhejiang provinces, respectively. During the planning and early construction stage, the railway was originally referred to as the Nanjing-Hangzhou Intercity Railway or Ning-hang Intercity Railway (宁杭城际铁). Recent publications don't use the "intercity" designation anymore, perhaps in recognition of the fact that the railway will be used not only by local trains but by long-distance trains as well. The line is 249 km long (including 147 km in Jiangsu and 102 km in Zhejiang) and has 11 stations: Nanjing Station, Jiangning District, Lishui County, Liyang, Yixing in Jiangsu; and Changxing County, Huzhou South, Deqing County, Yuhang District and Hangzhou East in Zhejiang. The line is the first direct railway between Nanjing and Hangzhou and reduced travel time by rail from nearly two hours to 50 minutes as direct trains no longer need to travel through Shanghai. Construction began in 2008 and the line was opened on July 1, 2013. http://crh.gaotie.cn/hangyong/2011-03-04/6280.html

Changjiang Delta Region. This boundary was modified in Figure 6 to match the research goal of the thesis.

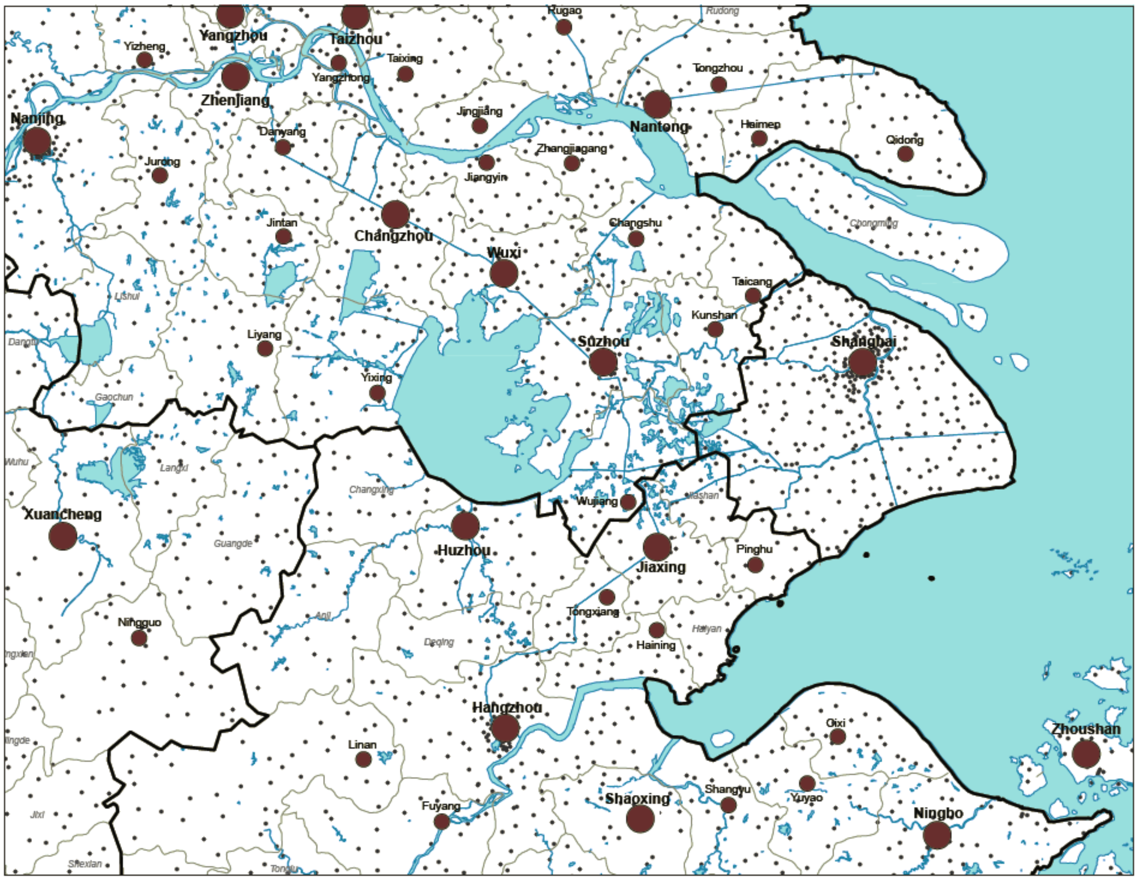


Figure 5. Cities, towns, and townships in the Changjiang Delta Region in 2000.
Source: Rowe et al., 2013, *Methodological notes on the spatial analysis of urban formation*, Harvard University Graduate School of Design.

From the stand point of functioning as an 'urban regional network' and in harmony with both environmental and life-style circumstances, a well-developed and connected mix of big, medium-sized, and smaller urban settlements appears to offer advantages of alternative life style domains, more compact and intensive development, less pervasive cover of non-urban assets such as agricultural and conservation areas, and the diseconomies of excessive scale and over population of particular cities. However, this is also conjectural and requires testing and further analysis. Moreover, at present in the Changjiang delta, the dynamics of development among settlements of varies size is in a state of flux.

Based on the understanding of the present state regional urban structure of the Changjiang Delta Region, in Chapter four, the research further evaluated and assessed the future growth potentials. It was followed by urban growth model prediction, including model identification, baseline construction, and scenario construction. Then the predicted results were reevaluated to provide suitable policy recommendations.

4. The study area

The study area of the Changjiang Delta Region covers an area of 75,900 km2 of territorial land area and 10,200 km2 of water bodies. It includes 16 regional-level cities, 28 county-level cities, and some 1,700 towns. The total population was about 65 million in 2010. The average annual precipitation is between 1,000 and 1,500 mm, and the average annual temperature is between 14 to 17 degrees Celsius. The region is composed of an alluvial flat land located in a transitional zone between the Changjiang and the East China Sea. The study boundary was drawn to include 62 regional level cities and counties from three provinces, Jiangsu, Zhejiang, and Anhui, and one municipality, Shanghai. Additionally, there were no large cities within a buffer zone of 100 km beyond the study area. This helps to rule out the possibility of significant gravitational influence on the internal structure of the urban network.

Figure 6 shows the administrative boundary of the entire study area with 62 cities and towns[3]. The rectangular outline is the boundary of the study area for urban growth modeling. If

[3] Zhoushan was removed from the study area because of its island condition, separating the city from the rest of the region with only ferry connections. Shexian and Tonglu were also removed from the study area because their whole administrative boundaries are located outside of the outline boundary. Thus the 65 cities and towns showing in Figure 6 became 62 after removal of Zhoushan.

partial territory of the cities and towns was situated outside of the boundary outline, then the growth model was adjusted to take account the prorated portion of growth. Population, Gross Domestic Product, and other infrastructural measures were counted as if the whole cities and towns were located within the outline. The outline was so set to take into consideration of economic, environmental, and social conditions of the region.

Figure 6. The study area of the Changjiang Delta Region including 62 regional level cities and towns.

Chapter 4. Assessment of potential future development patterns of Changjiang Delta region

This chapter assesses different approaches for modeling potential future urban development patterns. Of the alternatives, Cellular Automata, a land-based model using algorithmic processes, appears to be the most appropriate for this investigation. A Scenario Cellular Automata model, developed from SLEUTH, a specific type of generic Cellular Automata model, is utilized to address different scenario conditions. The Scenario Cellular Automata model projects four selected scenarios of future urbanization patterns of Changjiang Delta region from 2011 to 2030. The predicted outcomes are compared with three Baselines Measures: Environmental suitability, economic performance, and cultural amenity. The comparison reveals the impacts of future urbanization patterns on the three baselines. The applications and contributions are then discussed.

1. Assessment of different modeling approaches

In order to provide for structured empirical speculation about future potential pattern of urban settlement, an appropriate platform for modeling urban growth and change needs to be established. Among broad categories of considerations for this are: gravity models, agent-based models, and the use of algorithmic processes such as Cellular Automata.

The most fundamental features of models are a selective attitude to information and a suggestive nature to outcomes. The selective attitude not only eliminates noise, error, and highly correlated features, but also less important signals (Haggett & Chorley, 1967). The selected features of models resemble the real world in some aspect, a phenomenon also known as structured approximations of reality. A good model represents the real world in a simplified but adequate way (Liu, 2009). The suggestive nature, in the circumstance of a predictive model, provides concrete evidence of the way in which "everything affects everything else", more or less (Lowry, 1965).

The earliest use of models can be traced back to von Thunen's agricultural location in 1826, which included only three variables: distance, price, and land use. This German stream of analysis directly influenced the first urban growth model in 1909, which was written in Alfred Weber's 'Theory of Industrial Location' identified the optimal location for manufacturing plant. The Central Place Theory, the Multiple Nuclei Model, and Sector Model were all classical models of urban growth (Hagerstrand, 1967). In the late 1950s and continuing in 1960s, the quantitative revolution in geography made the use of models widespread in urban geography among other fields (Batty, 1981).

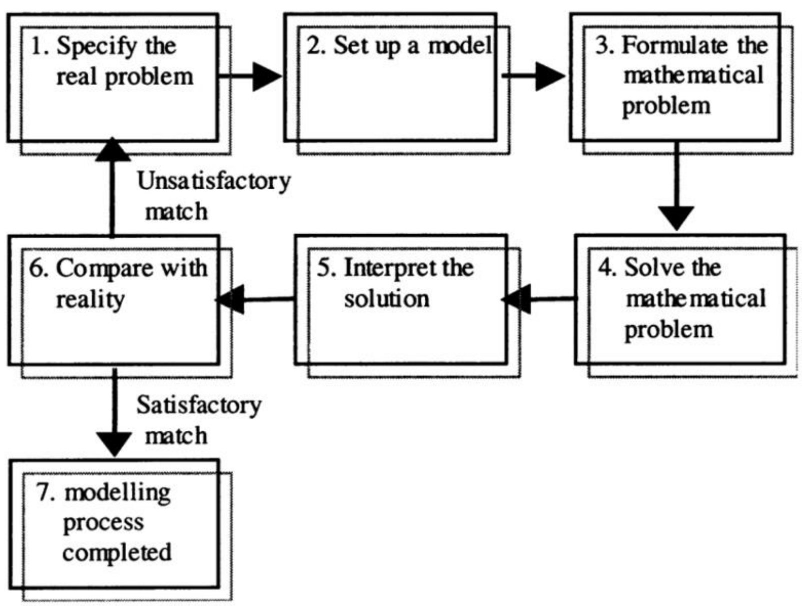


Figure 1. A flow chart showing the various stages of the modelling process.

a. Gravity models

At their core, Lowry or gravity models allocate the spatial distribution of urban growth based in a version of 'social physics' where the attractiveness of particular locations depend on their populations and distance apart. Distance is usually measured as a time cost and is seen to be inversely proportional to the distance from other interactive locations. The case in Figure 2 is for nine locations with different hypothetical populations and distances. Notice in this case the 'Queen's Matrix' was applied where distance between diagonal cells was calculated with a discounted value.

P = Population; A = Accessibility; At = Attractiveness; d = distance;
n = Number of spatial units

$$At_i = \sum_{j=1,n} A_{ij} = \frac{P_i + P_j}{d_{ij}^{e}} \text{, where } e = 2$$

Population Vector

	1	2	3	4	5	6	7	8	9
P	1	3	2	4	4	3	2	1	1

Distance Matrix

	1	2	3	4	5	6	7	8	9
1	0	1.0	2.0	1.0	1.4	2.8	2.0	2.4	2.8
2	-	0	1.0	1.4	1.0	1.4	2.4	2.0	2.4
3	-	-	0	2.4	1.4	1.0	2.8	2.4	2.0
4	-	-	-	0	1.0	2.0	1.0	1.4	2.4
5	-	-	-	-	0	1.0	1.4	1.0	1.4
6	-	-	-	-	-	0	2.4	1.4	1.0
7	-	-	-	-	-	-	0	1.0	2.0
8	-	-	-	-	-	-	-	0	1.0
9	-	-	-	-	-	-	-	-	0

Districts of Spatial Units

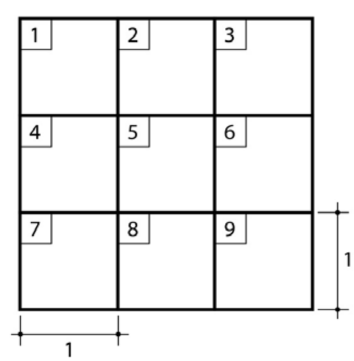


Figure 2. The Gravity Model 1.

Figure 3 shows the resultant of this formulation for the nine location case, with a conversion from raw score into relative attractiveness, centered on location 5 with the highest score, followed by location 4, and so on. In principle, this would mean that the 'growth potential' of these locations, or their 'importance', would conform to this relative format (Rowe, 2013).

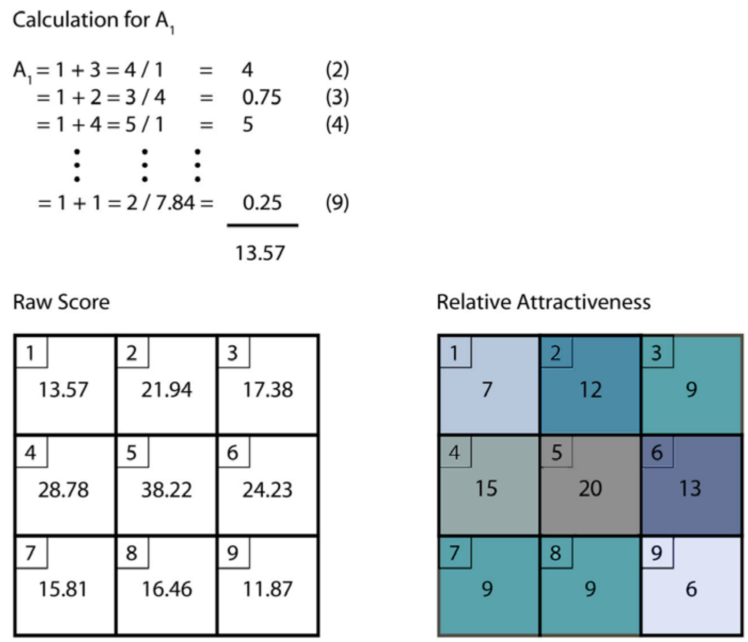


Figure 3. The Gravity Model 2.

Figure 4 shows different expressions of the gravity model in terms of a composite measure of accessibility. The differences, while not entirely fundamental, reflect different applications with regard to transportation and access to public facilities.

Dalvi and Martin, 1976

$$A_i = \frac{\sum_{j=1}^{n} W_j e^{-\beta cij}}{\sum_{j=1}^{n} W_j}$$

Ai: accessibility of zone i to opportunities in zones j=1,…n
Wj: measure of attractiveness of zone j
Cij: cost of travel from i to j

Tsou et al., 2005

$$E_{ij(k)} = P_k \times W_{j(k)} \times S_{ij}^{-2}.$$

Pk: preference of residents to the kth type of public facility
Wj(k): relative effect of the public facility j(k) according to its size and type
Sij: cost of travel from i to j

Figure 4. Variations of the Gravity Model.

The limitation of gravity models includes an inability to easily produce a yearly-based result, and the method is essentially backward tracing, requiring a predetermined end result usually related to population.

b. Agent-based models

Agent-based models, also call individual-based models, simulate the operations and interactions of multiple agents in an attempt to re-create and predict the appearance of complex phenomena. One of the earliest agent-based models is Thomas Schelling's segregation model. However, it did not become popularized until intensive computational capacity dramatically expanded in the 1990s. Since the turn into the twenty-first century, agent-based models have been deployed in urban planning to simulate pedestrian movement in the urban environment.

Agent-based models' elemental components are agents, pieces of software code with attributes that describe their condition and characteristics and that govern their behavior. The main characteristics include: agents existing in some space; agents possessing some discrete confines that separate them from the environment in which they exist; agents having sets of attributes states that describe their characteristics. Further, information exchange is much more explicit. Agents can, in many instances, 'communicate' with other agents as well as with their environment.

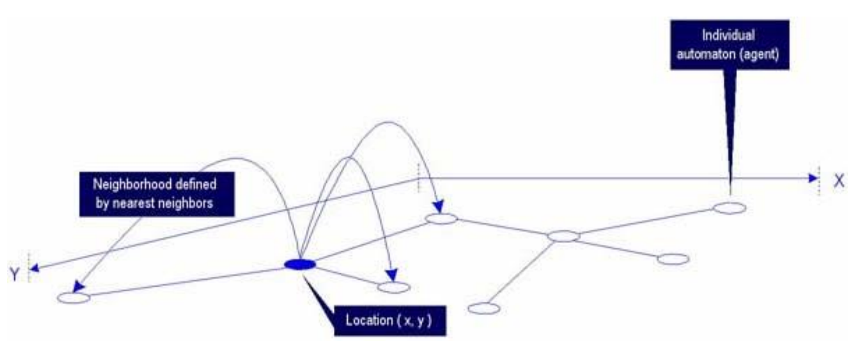


Figure 5. Diagram for agent-based models.

Agent-based models most often involve human agents with potentially irrational behavior, subjective choices, and complex psychology processes. In other words, an Agent Based Model could be influenced by soft factors that are difficult to quantify, calibrate, and sometimes justify. This may constitute a major source of problems in interpreting the outcomes of simulations (Bonabeau, 2002).

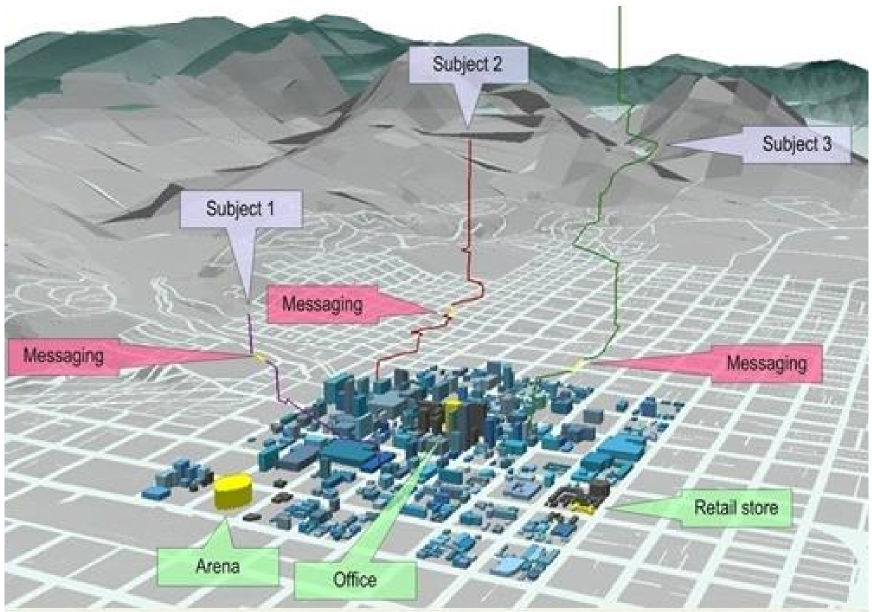


Figure 6. Agent-based models simulation.
Source: Geosimulation, Dr. Paul M. Torrens, Dept. Geographical Sciences and Institute for Advanced Computer Studies, Univ. Maryland. http://www.geosimulation.org/
http://www.geosimulation.org/space-time-analysis/

c. Cellular Automata

Cellular Automata were first devised by John von Neumann and Stanislaw Ulam. The former is the originator of game theory, and pioneer in set theory, quantum mechanics, and the specification of electronic computers. The latter worked on Monte Carlo simulation and the hydrogen bomb as a part of the Manhattan Project with Edward Teller, and was influential in set theory and number theory in the 1940s as a framework for investigating the logical underpinnings of life. One can say that the ‘cellular’ comes from Ulam and the ‘automata’ comes from von Neumann (Rucker, 1999). Von Neumann and Ulam were interested in exploring whether the self-reproducing features of biological automata could be reduced to purely mathematical formulations, whether the forces governing reproduction could be reduced to logical rules (Sipper 1997).

A cellular automata model, even though the principles behind it are not directly related to the social economic factors, can more accurately reflect the growth pattern that are caused by those factors. In a nutshell, Cellular Automata mimics the result of an urbanization process through a scientific algorithm. It doesn’t prove the causality of urban growth that we observe but rather simulates its reality. The association is observable in the calibration process. Cellular Automata provides a platform for a way of examining this forward projection of alternatives. Further, sensitivity studies of policies using ‘difference in difference’ methodologies provide Celluar Automata models a broader application domain in the field of urban planning and design (Liu, 2009). In short, of the alternative approaches, the use of Cellular Automata appears to be the most appropriate for this investigation. It requires relatively few assumptions, generates results in an incremental measure allowing concentrated localized analysis and is responsive to baseline conditions of both large- and small-scaled settlement.

Figure 7 depicts the two-dimensional array aspect of Cellular Automata under two different neighborhood arrangements in a thirteen by thirteen cell configuration. The first is the ‘Moore’ neighborhood, or so-called ‘Queen’s Matrix’, and the second is the ‘von Neumann’ neighborhood, or ‘Rook’s Matrix’, named for their respective proponents. The capacity of the configuration given by the possible lattice sites is 2^{169}. Each cell in cellular automata has a neighborhood of adjacent cells that surround it. Certain rules, included alongside the model in a transition table, give the state of any cell at any given time in the evolution of the model. Information exchange is mediated through the neighborhood and time proceeds through discrete steps of t; t+1; t+2 … ; t+n.

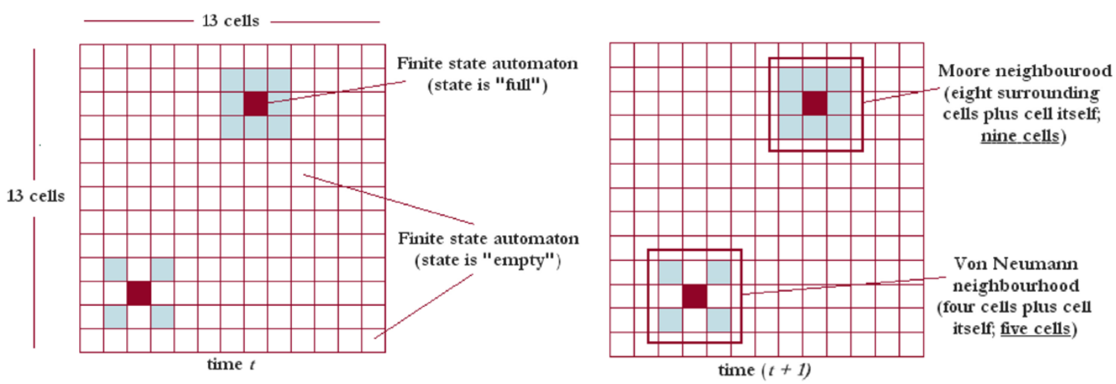


Figure 7. Moore and von Neumann Neighborhoods in Cellular Automata after Torrens, 2000.

Figure 8 schematically describes a particular Cellular Automata model called SLEUTH – Slope, Land Cover, Elevation, Urbanization, Transportation, and Hillside – developed by Clarke in 1997 (Clarke et al., 1997 and Clarke et al., 1998). It is comprised of two models: an urban growth model and a land cover model. The Cellular Automata works in a grid space of homogenous cells, with a Moore neighborhood of eight cells and two cell states (urban vs. non-urban), and five transition rules that act in sequential time steps. These transition states are further described by coefficient values, including the dispersion coefficient, the breed coefficient, the spread coefficient, and a slope coefficient, and the road gravity coefficient.

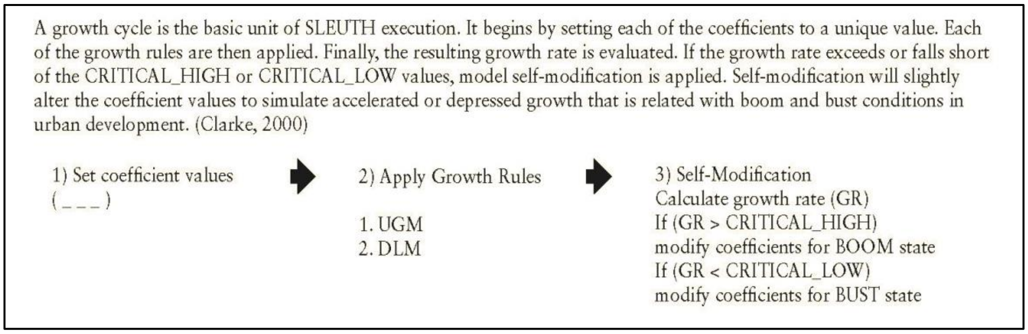


Figure 8. The SLEUTH Cellular Automata from the National Center for Geographic Information and Analysis, 2001.

Figure 9 describes aspects of these five coefficients that determine transition states among the cells in the model. For instance, the 'dispersion coefficient' controls the number of times a pixel (cell) will be randomly selected for possible urbanization; the 'slope coefficient' portrays the reality that it is easier to build on lower than higher slopes; and the 'road gravity coefficient' assesses the distance from a pixel (cell) to a road, including of varying capacities.

Figure 10, 11, 12, 13, 14, and 15 describe growth rules which are applied to an initial input data configuration of the study area setting. Two measures of suitability affect the likelihood of urbanization throughout the process, defined by exclusion layers (eg. water, swamps, etc.) and by slope, especially above 21 percent. The growth rules include: spontaneous growth or random urbanization of land parcels (cells); new spreading centers; edge growth that stems from new spreading centers; and road-influenced growth determined by the transportation infrastructure, weighted in favor of accessibility. In addition, there is an additional growth rule, prompted by high and low growth rates; or 'boom' and 'bust' periods.

Dispersion coefficient

1.1 Spontaneous growth: the dispersion_coefficient (previously referred to as diffusion_coefficient) controls the number of times a pixel will be randomly selected for possible urbanization.

Applied value is derived from coefficient by:

$$dispersion\_value = ((dispersion\_coeff * 0.005) * sqrt\ (rows\_sq + cols\_sq))$$

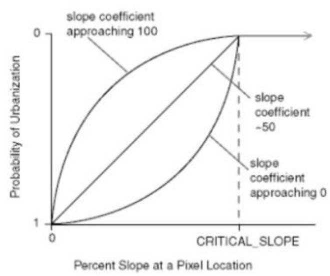
so that dispersion_value at its maximum (dispersion_coeff == 100) will be 50% of the image diagonal.
dispersion_value is applied to spontaneous growth by:

```
for (k=0; k<dispersion_value; k++)
{
        select pixel (i,j) at random
try to urbanize (i,j)
}
```

Slope coefficient

Lower slopes are easier to build upon that steeper slopes, and eventually, a percent slope will be reached at which building is impossible (CRITICAL_SLOPE). The relative pressure to build upon ever steeper slope is dynamic and related to the proportion of flatland available and the steeper area's proximity to an already established settlement.

The slope_coefficient affects all growth rules in the same way:
When a location is being tested for suitability of urbanization, the slope at that location is considered. Instead of enforcing a simple linear relationship between the percent of slope and urban development, the slope_coef acts as a multiplier. If the slope coefficient is high, increasingly steeper slopes are less likely to urbanize. As the slope coefficient gets closer to zero, an increase in local slope has less affect on the likelihood of urbanization.



Road gravity coefficient

Road influenced growth: the maximum search distance for a road from a pixel selected for a road trip is determined as some proportion of the image dimensions.

Applied value is derived from coefficient by:

$$rg\_value = (rg\_coeff/MAX\_ROAD\_VALUE) * ((row + col) / 16.0)$$

where MAX_ROAD_COEFF_VALUE is defined as 100, and (row, col) are the row and column pixel counts, so that rg_value at its maximum (rg_coeff == 100) will be 1/16 of the image dimensions. If the rg_coeff value is less than 100, then the rg_value will be some proportion less than 1/16 of the image dimensions.

rg_value is applied to road influenced growth by:

$$max\_search\_index = 4 * (rg\_value * (1 + rg\_value))$$

where rg_value defines maximum number of neighborhoods from selected newly urban pixel to search for a road.

The first neighborhood (rg_value == 1) is made up of the selected urban pixel's adjacent 8 cells. The second neighborhood (rg_value == 2) would be the 16 pixels outwardly adjacent to the first neighborhood, etc. In this way the outward search for a road will continue until (a) a road is found, or (b) the search distance is greater than max_search_index.

Figure 9. Transition states and their coefficients from the National Center for Geographic Information and Analysis, 2001.

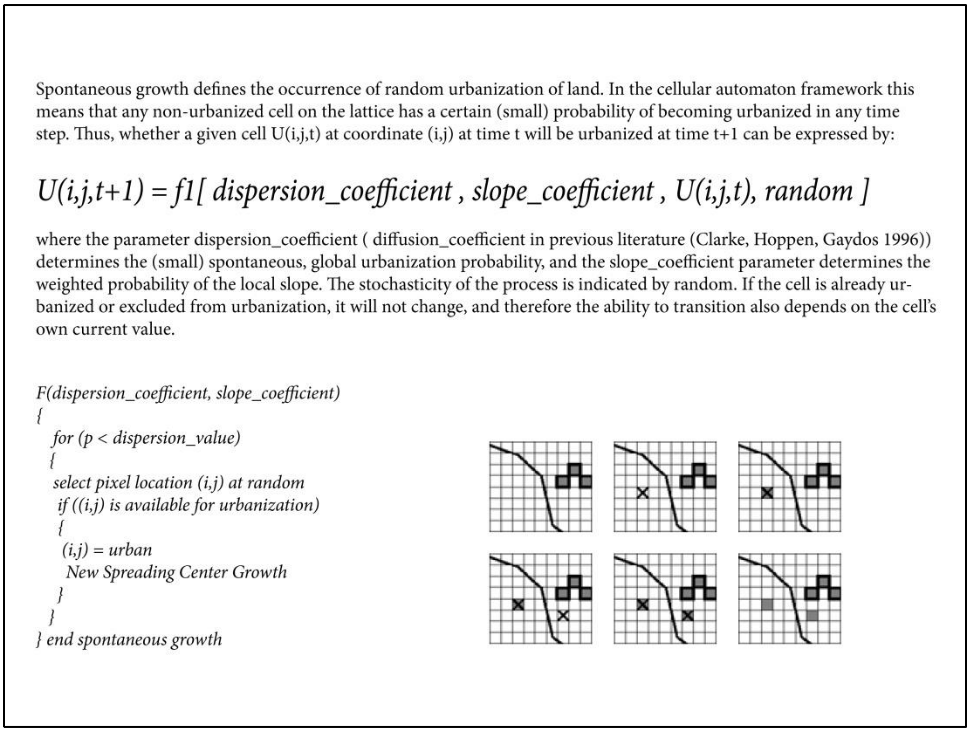


Figure 10. Spontaneous growth rule from the National Center for Geographic Information and Analysis, 2001.

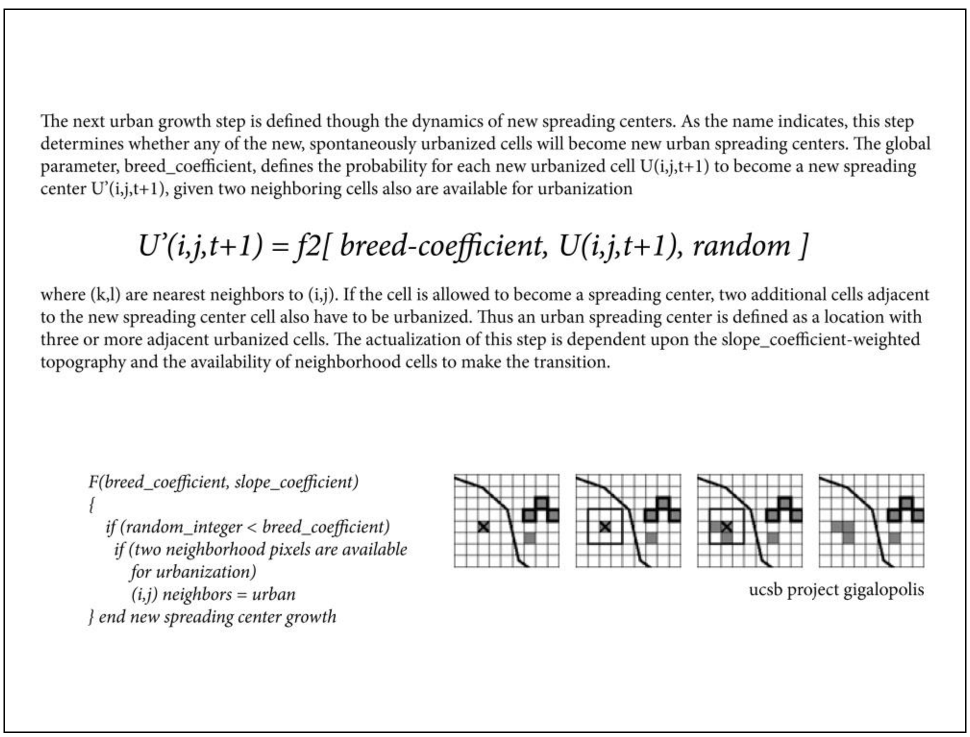


Figure 11. Spreading center growth rule from the National Center for Geographic Information and Analysis, 2001.

Edge-growth dynamics define the part of the growth that stems from existing spreading centers. This growth propagates both the new centers generated in step ii in this time step, time (t+1), and the more established centers from earlier times. Thus, if a non-urban cell has at least three urbanized neighboring cells, it has a certain global probability to also become urbanized defined by the spread_coefficient, given it is possible to build on the cell (slope_coefficient). Thus this edge growth can be expressed by

U(i,j,t+1) = F3[spread_coefficient, slope_coefficient, U(i,j,t), U(k,l), random]

where (k,l) belongs to the nearest neighborhood of (i,j).

```
F(spread_coefficient, slope_coefficient)
{
  for (all non-edge pixels (i,j))
    if ((i,j) is urban) and (random_integer
      < spread_coefficient)
      if (at least two urban neighbors exist)
        if (a randomly chosen, non-urban
          neighbor is available for urbanization)
         (i,j) neighbor = urban
} end edge growth
```

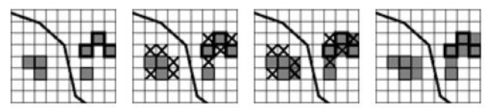


Figure 12. Edge growth rule from the National Center for Geographic Information and Analysis, 2001.

The final growth step, road-influenced growth, is determined by the existing transportation infrastructure as well as the most recent urbanization done under steps i, ii and iii. With a probability defined by breed_coefficient, newly urbanized cells (at time t+1) are selected, and the existence of a road is sought in their neighborhoods. If a road is found within a given maximal radius (determined by road_gravity_coefficient) of the selected cell, a temporary urban cell is placed at the point on the road that is closest to the selected cell. Next, this temporary urban cell conducts a random walk along the road (or roads connected to the original road) where the number of steps is determined by the parameter dispersion_coefficient. The final location of this temporary urbanized cell is then considered as a new urban spreading nucleus. If a neighboring cell to the temporary urbanized cell (on the road) is available for urbanization, it will happen (randomly picked among possible candidates). If two adjacent cells to this newly urbanized cell are also available for urbanization it will happen (randomly picked among candidates). Thus the creation of the temporary urbanized cell on the road is defined by

U'(k,l,t+1) = f4.1[U(i,j,t+1), road_gravity_coefficient, R(m,n), random]

where i,j,k,l,m, and n are cell coordinates, and R(m,n) defines a road cell. The random walk on the road may be expressed by

U"(i,j,t+1) = f4.2[U'(k,l,t+1), dispersion_coefficient, R(m,n), random]

where (i,j) are road cells neighboring (k,l). If we define the location of the temporary urbanized cell at the end of the random walk by (p,q), the new adjacent urban spreading center will be defined by

U'"(i,j,t+1) = f4.3[U"(p,q,t+1), R(m,n), slope_coefficient, random]

Two additional adjacent urbanized cells may be added using

U""(i,j,t+1) = f4.4[U'"(p,q,t+1), slope_coefficient, random]

where (i,j) and (k,l) belong to the nearest neighborhood of (p,q). Note how this step is similar to notation 3.

Figure 13. Road-influenced growth rule 1 from the National Center for Geographic Information and Analysis, 2001.

The four steps above are collectively referred to as a road trip. Each attempt to select a newly urbanized pixel to move to a road is a new road trip. The number of attempted road trips in any given growth cycle is determined by the breed_coefficient.

```
F(breed_coefficient, road_gravity_coefficient,
dispersion_coefficient, slope_coefficient)
{
 for (p <= breed_coefficient)
  {
   road_gravity = value which is a function of
   image size and road_gravity_coefficient
   max_search = maximum distance, determined by
          road_gravity, for which a road pixel is searched
          (i,j) = randomly selected pixel, urbanized within the
          current growth cycle
          road_found = search outward from (i,j), up to
          max_search, for a road pixel
     if (road_found)
     {
      walk along the road, in randomly selected
       directions, for a number of steps determined
         by the road_value and the
         dispersion_coefficient
      if (a neighboring pixel is available for urbanization)
       (i,j) neighbor = urban
       if (two neighbors of the newly urban pixel
         are available for urbanization)
         two urban pixel neighbors = urban
} } } end road-influenced growth
```

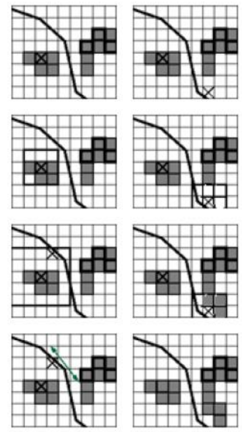
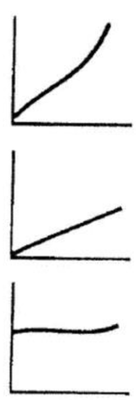


Figure 14. Road-influenced growth rule 2 from the National Center for Geographic Information and Analysis, 2001.

Growth coefficients do not necessarily remain static throughout an application. In response to rapid or depressed growth rates, the coefficients may be increased or decreased to further encourage system wide growth rate trends.

A second level of growth rules, termed self-modification rules, is prompted by an unusually high or low growth rate. The growth rate is the sum of the four different types of growth defined by the model for each model growth cycle, or "year." The limits CRITICAL_HIGH and CRITICAL_LOW (defined in the scenario_file) kick off an increase or decrease in three of the growth control parameters: dispersion, breed, and spread. If the growth rate exceeds the CRITICAL_HIGH, the coefficients are increased by a multiplier greater than one: BOOM. This increase imitates the tendency of an expanding system to grow ever more rapidly. If the growth rate falls below the CRITICAL_LOW, the coefficients are decreased by a multiplier less than one, BUST, causing growth to taper off as it does in a depressed or saturated system.



Rapid Growth: greater than 'critical' number of hectares per year
DIFFUSION is multiplied by a constant > 1.0
SPREAD is multiplied by a constant > 1.0
BREED is multiplied by a constant > 1.0

Normal Growth: between rapid and little or no growth
If average SLOPE > 10% , increase SPREAD
ROAD_GRAVITY increases by percent of road network
SLOPE_RESISTANCE increase by 0.2 X percent of urban land available

Little or No Growth: annual growth rate is less than 'critical' value
DIFFUSION is multiplied by a constant < 1.0
SPREAD is multiplied by a constant < 1.0
BREED is multiplied by a constant < 1.0

Figure 15. Addition of growth rule from the National Center for Geographic Information and Analysis, 2001.

2. Scenarios of potential developments

Evolution of scenario modeling

Modeling of potential future urban settlement patterns in the Changjiang Delta Region was taken up under specific scenarios. Each of these scenarios prescribed a basic trajectory of development with unique features. Also, all represented plausible development trends towards favorable outcomes of development with regard to land cover, scale variety, and association with particular places and settings.

In addition to a basic scenario involving modeling of current trends, other projected alternative circumstances descriptive of the Changjiang Delta regional network can be characterized in the following manner:

1. A few large cities grow larger. Other developments will be constrained. Shanghai, the dragon head, together with Nanjing, Hangzhou, Suzhou, Wuxi, and Ningbo are considered large cities. In an extreme circumstance, the pro-growth area can be confined to fewer provincial capital cities and municipalities.

2. Big cities growth will be constrained. Selected medium to small size cities expand and are networked. The selection of the medium and small size cities was based on geographical distribution.

3. Development along transportation (railway/highway) corridors: The high-speed rail network was an established transportation corridor to follow. For example, one transportation corridor is from Shanghai to Nanjing, the other is from Shanghai to Hangzhou.

4. Life style attractions to places of high culture / environment amenity, such as Lake Tai and cities around it.

5. Environmental concerns: Limitation on spatial development, with barriers based on resource value.

6. Uneven Foreign Direct Investment (FDI), with centered and spillover areas, depends on the extent of out-of-region financial support. Shanghai is clearly the largest FDI recipient. However, the spillover effect has reached to Suzhou, Hangzhou, Jiaxing, among other cities.

7. Disaster Prevention and Resiliency of Cities.

8. Uneven distribution of human resources and new technologies. Dependence on domestic human capital: Nanjing and Shanghai both ranked top among the Chinese cities with leading universities and higher education in general.

Description of four selected scenarios

Four scenarios were proposed based on the above circumstances. They were: 'development corridors', 'development corridors, plus big city growth', 'environmental system concerns, plus development corridors', and 'disaster prevention, plus development corridors'. The reasons why development corridors were selected for all four scenarios were that they are already in place via the high-speed rail and highway network and will continue to be one of the most influential factors of urban and regional growth of Changjiang Delta region.

a. Scenario 1: development corridors

The multi-centered regional urban formation in the Changjiang Delta was identified by scholars exploring the nature of the spatial economic structure of the region (Marton, 2000; Zhang, 2000). In the 1990s, county-level cities developed faster than peripheral areas. Provincial level cities and other large cities' development were also stimulated. The results were widened regional disparities. Zhang (2000) suggested using morphological shapes to represent the regional space structure. Essentially, these morphological shapes were formed by nodes and links. The nodes were cities and the links were development corridors connecting the cities. In the early 2000, a ‘Z’ shape of morphological development corridors, mentioned earlier, became evident. It started from Nanjing at the northwestern corner of this region, through Zhenjiang, Changzhou, Wuxi, Suzhou, and Kunshan, connected with Shanghai at the mouth of Changjiang estuary. From Shanghai, it linked with Hangzhou to the southwest through Jiaxing. Then again it changed direction to the east connecting with Ningbo before reaching the hilly area of southern Zhejiang province.

The formation of the ‘Z’ shape started in the 1990s when ‘Hu-Ning’ highway, connecting Nanjing and Shanghai, was completed as one of the first highways built in China. Since then, it acted as an artery promoting economic growth by increasing the connectivity among the cities and towns between Nanjing and Shanghai. In July, 2013, Ning-Hang High-speed Rail (NHR) connecting Nanjing and Hangzhou launched its operation. This line reduced the travel time from Nanjing to Hangzhou from over two hours to 50 minutes.

There were other roads and bridges built to enhance connectivity of the region, for example, the Hangzhou Bay Bridge shorten the travel distance between Shanghai and Ningbo by 200 kilometers. Certainly, these connections can become more and more important. However, this scenario considered only major development corridors that link multiple cities within the region as well as neighboring provinces.

Thus, the four parts of the development corridors were identified as Nanjing to Shanghai, Shanghai to Hangzhou, Hangzhou to Ningbo, and Nanjing to Hangzhou. (Figure 16)

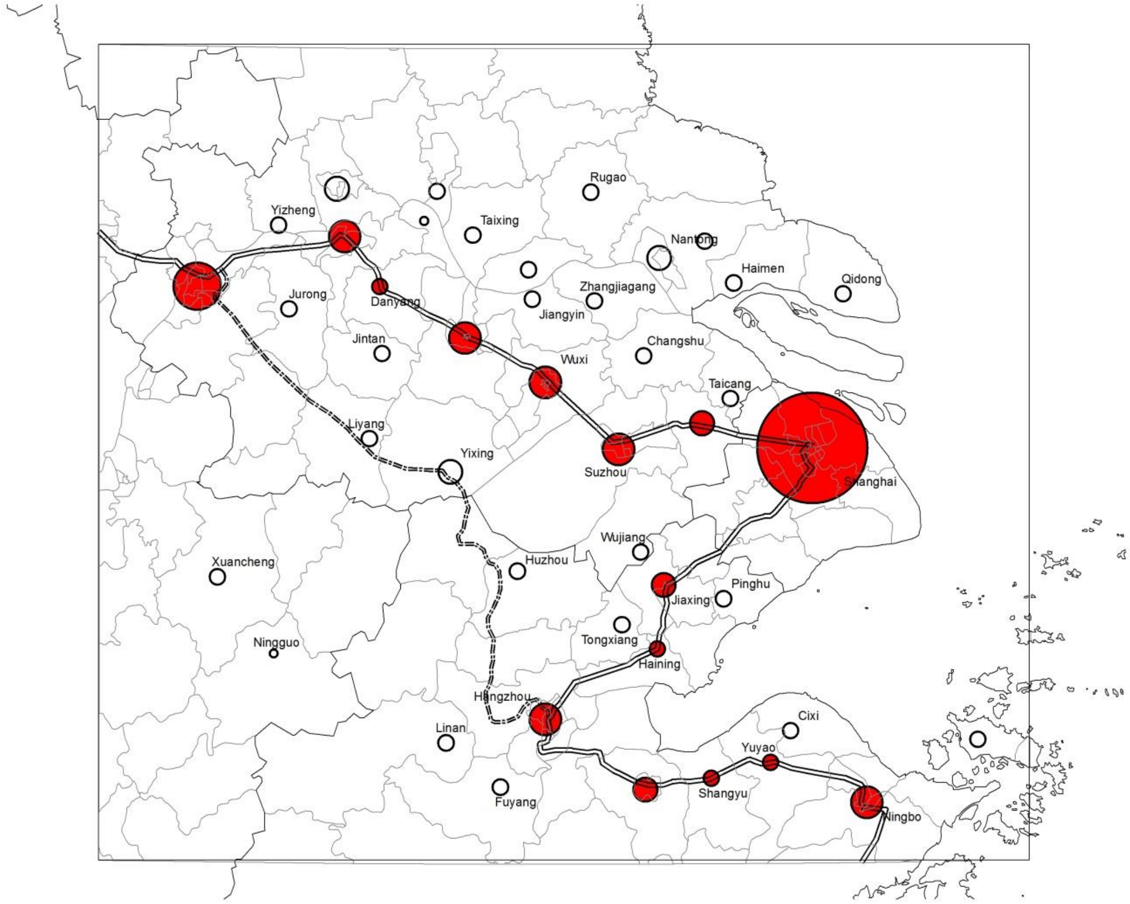


Figure 16. Scenario 1: development corridors.

b. Scenario 2: development corridors, plus big city growth

In 1923, Frank Lloyd Wright forecasted urban decentralization, announcing that the big cities were no longer modern. His peers in the 1920s argued that the capital cities of America's industrial revolution were built to last (Fishman, 1995). This debate didn't last long, by 1945, the relationships between the urban core and suburbia had already undergone a startling transformation (Fishman, 1995). Presently, contemporary city form has changed drastically which made it necessary to redefine the concept of city and put it in a regional scale to better understand the urban settlement.

China entered an era when cities grew rapidly in size and density. In the Changjiang Delta region, cities on average are denser than western counterparts, and big cities created more opportunities, attracting highly educated elites as well as migrant workers. The collaboration among cities to take advantage of regional competitive advantages and the dynamics of city-size distribution[1] are on the agendas of both central and local governments. For example, the empirical results show that the evolution of urban system in the Changjiang Delta has undergone primate, rank-size and primate distribution patterns. The primacy of Shanghai was the lowest in 2002, but the whole pattern of urban system shifted to primate distribution pattern again, which to a large extent reflects the corresponding adjustments of urbanization guidelines in China in the twenty-first century. In term of the relationship between city size and city growth, the whole urban system takes the form of convergent growth, which means the initial smaller cities grow faster than larger cities. However, the difference in city growth is not significant (Pu et al, 2009). In a way, the urbanization process in the Changjiang Delta has already taken the lead to improve human knowledge on urban growth at a regional scale (Zhang, 2000). Additionally, a temporal dimension is also crucial to comprehend the juxtaposition of movement and settlement.

[1] Urbanity is the engine of economic growth. With the rapid development of urbanization process across the world, the dynamics of city-size distribution has been a hot topic. The heated debates centering on the optimal city size have exerted impacts on urbanization courses in China. From several different perspectives, Pu investigates the spatio-temporal dynamics of city-size distribution in the Changjiang Delta during the period 1984-2002. From the long-term tendency, the number of cities over two times of the average size will greatly decrease to about 6%, and middle-sized cities will dominate the urban systems in the future. Generally speaking, it will take about 16 years for a non-city area to develop into a city with half of the average size. On the whole, the change of city-size distribution in the Changjiang Delta is becoming more even, and the tendency of spatial polarization and concentration is not the case. The spatial agglomeration in southern Jiangsu and Hangzhou Bay rim continues to be strengthened with the deepening of the policy opening to the outside world, which contrasts with the relative quiescence in northern Jiangsu and southern Zhejiang. (Pu et al., 2009)

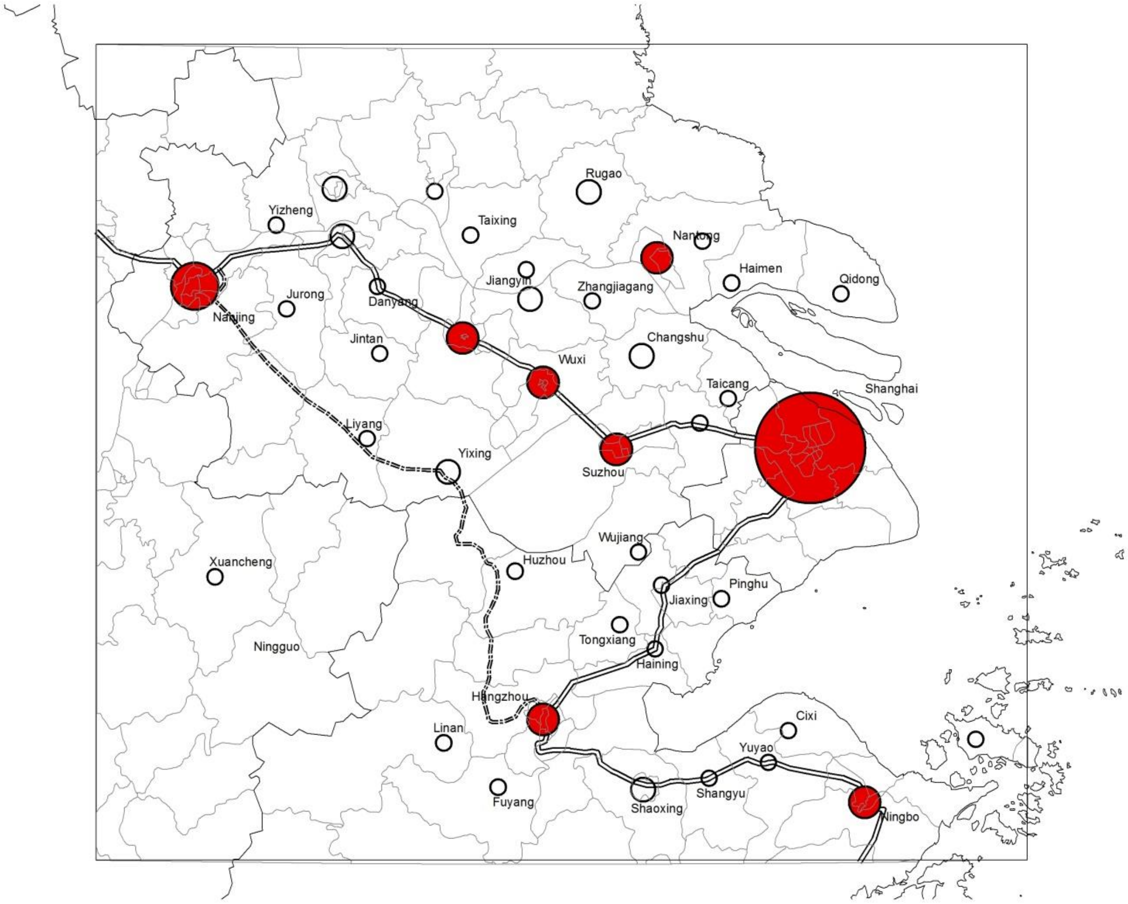


Figure 17. Scenario 2: development corridors, plus big city growth.

c. Scenario 3: ecological system concerns, plus development corridors

One of the aims of this research is to seek potential change in the present pattern of regional urban development especially with regard to environment performance. As mentioned, historically, Chinese used Feng-Shui's basic principle for site sections and urban settlements. It kept the balance of Yin and Yang to harmonize the flow of "Qi", which considers man, state, nature, and heaven, as stated earlier. It is comparable to a multi-disciplinary research in the modern days that incorporates consideration of population, economics, and the environment.

In the late 1960s and throughout 1970s, bottom-up planning, environmental concerns, and adaptive urban change found their way into the planning main stream (Hall, 2000). Ian McHarg's 'Design with Nature', Meadows's 'The limits to Growth', and Schumacher's 'Small is Beautiful' are all examples from other parts of the world. (McHarg, 1969; Meadow, 1972; Schumacher, 1973)

China, from the late 1970s, started the reform and opening up era under Deng Xiaoping's incremental policies typified by "Crossing the river by feeling for stones" (Gabriel, 1998). Not surprisingly, China took quite an opposite approach in terms of environmental concerns from what the western world chased after at the time. The goal for industrialization and modernization was built on top of sacrificing environment, much as had occurred much earlier in the west.

Declination of environmental quality is often associated with modern development. In the Changjiang Delta region, the less well-controlled development appears in conurbated areas between well-managed cities and towns, often causing adverse environmental consequences and economic inefficiencies (Rowe, 2011). Rowe proposed an alternative model of urban formation: a well-networked arrangement of cities and towns at different urban scales, upwards of 50,000 inhabitants at the smaller scale and with relatively few large cities in excess of one million inhabitants (Rowe, 2011). A well-networked region requires efficient inter-city transportation, sustainable land use patterns, and more importantly, protection of environmental sensitive location.

In this scenario, the forest ecosystem was applied to the urban modeling criteria. As such, there was zero tolerance to develop in any designated forest land. The reasons why forest land was selected as a proxy for ecological system were twofold: first, compared to crop land which changes more frequently, forest land remained relatively stable during the research time horizon; second, forest land is also one of the most effective countermeasures of air pollution and smog.

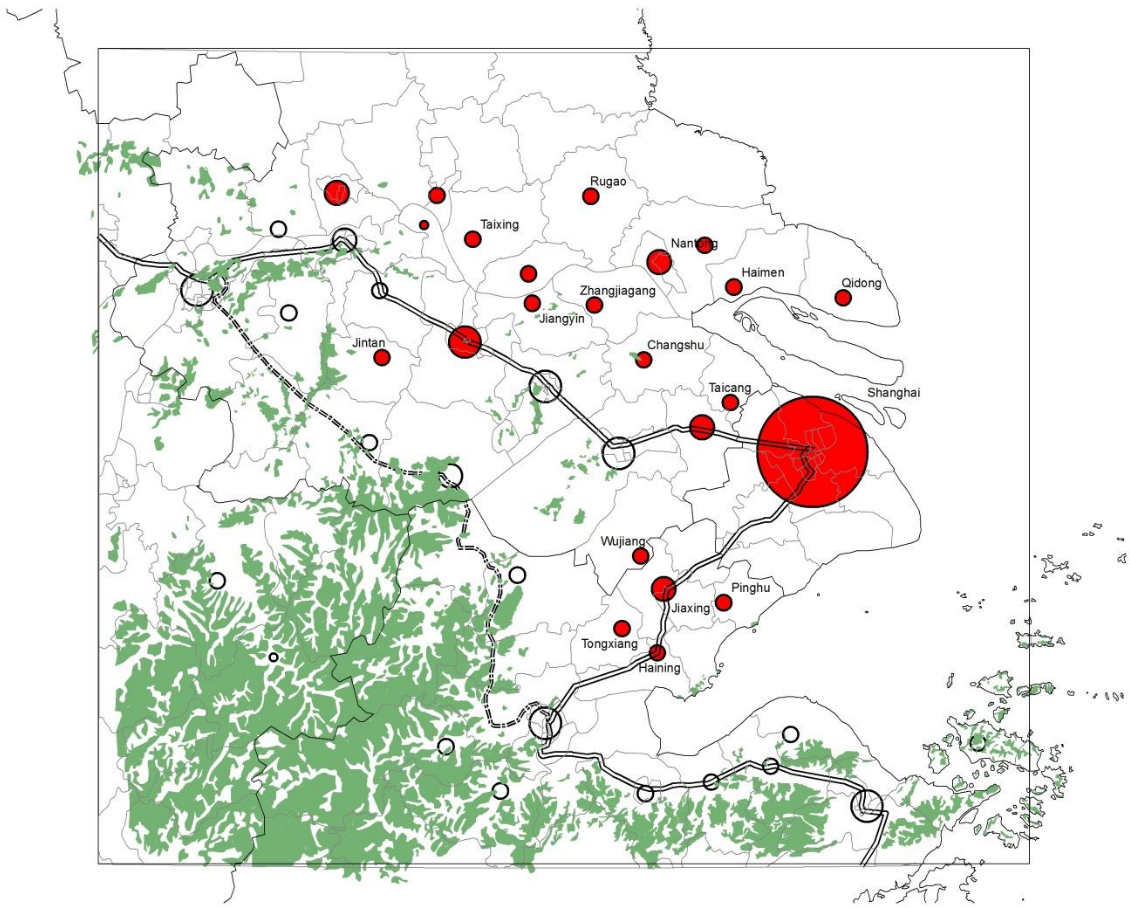


Figure 18. Scenario 3: ecological system concerns, plus development corridors.

d. Scenario 4: disaster prevention, plus development corridors

Disaster prevention has become increasingly more important as natural disasters of many kinds, in recent years, destroyed human habitats of various cultures. Throughout human history, the natural forces have caused numerous catastrophes buried lives, cities, and civilizations. As cities grow bigger and urbanization brings higher concentrations of humanity, the consequences of these events potentially rise substantially. Preventive action is critical in the process of directing future urbanization. Consequently, simply avoiding development on disaster-prone locations can preclude many unnecessary costs, which precluded many harmful events to the individuals who live in the area. Fukushima's nuclear explosion caused by a tsunami is one example of the extreme penalties experienced of natural disasters. New Orleans, another good example, is even under discussion as to whether or not it is a place appropriate for living (Munasinghe, 2007). In other regions, Nepal, the recent earthquake also gives indication where urban growth could avoid potential damages from natural forces. In the Changjiang Delta Region, earthquake and fault lines, as well as flooding are the major hazards, the latter aggravated by land-surface subsidence (Figure 19).

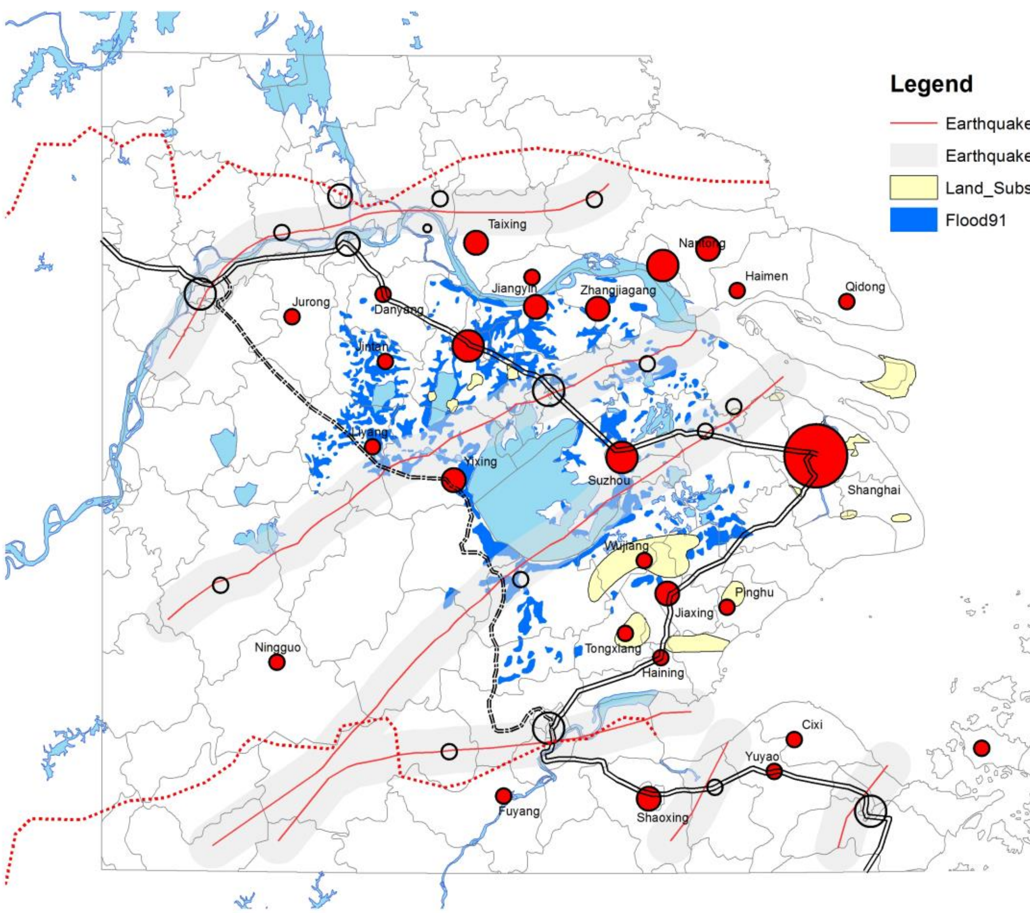


Figure 19. Scenario 4: disaster prevention, plus development corridors.

3. Data collection and processing

a. Land use pattern projection and urban development

Many scholars have investigated the relationship between urbanization processes and land use patterns as the basis for providing management recommendations for government and policy makers (Marton, 2000; Sorensen & Okata, 2011; Webster, 2012). The manner in which land is allocated is even more important than the magnitude of land conversion from agriculture to urban use (Bertaud, 2007). Though it is hard to justify which region has a better land-use pattern because each instance of urbanization is facing different circumstances, evidence has revealed that China, among other East Asia countries, developed relatively denser and functionally more efficient cities at least in certain regards. By no means, this is to say that these regions achieved best practice. At both the city scale and the regional scale, China is at a critical moment to implement appropriate development policies to direct and guide the future improvement of urban formation.

To measure and evaluate urban development and urban form, one group of researchers use indicators. For example, 'urban land consumption per capita' is an indicator of urban form change. Historically, China's major cities have a lower number than other major cities in the world. However, this started changing in the 1980s. Measured by this indicator, Tianjin, for instance, has a thirty-four percent increase from 1988 to 2000 (Bertaud, 2007). Wei et al. studied 'urban carrying capacity', it provides policy makers key conceptual underpinnings to improve urban sustainability (Wei, 2016). Another useful indicator is 'urban intensity' measured by four related concepts: compactness, diversity, density, and connectivity. Together they lead to a single idea when considering spatial distributions potentially in a virtuous manner with regard to resource consumption, economic opportunity, social integration and environmental performance. (Guan & Rowe, 2016)

Another group of scholars focused on simulation and projections. (Liu, 2009; Samat & Elhadary, 2011) However, relatively few have done scenario-based simulation together with basic 'carrying capacity' type investigation. The merit of this method can avoid the common problem of the generic model prediction pitfall by virtue of its more general applicability.

b. Data processing

Time series and land cover datasets were created for the years of 1950, 1970, 1980, 1990, 2000, and 2010. 1950 and 1970 were later dropped from the model calibration process because they represented a pattern of urban growth that dramatically differed from the post-economic reform era. Remote sensing images, historical maps, scanned planning, and geospatial data were collected and georeferenced. To specify standardized land-cover classes, on-screen visual interpretation was carried out using remote-sense images from the Landsat 5 and Landsat 7 series. The data sets were downloaded from the civilian Earth observation satellite, launched in July 23, 1972. Landsat 5 was launched in 1984 and delivers global data of Earth's land surfaces for more than two decades. The Landsat 7 was launched in 1999. The two sets of images were used together to compensate for the weather-related unrecognizable portion of the available images.

The data were processed in the ArcMap environment and georeferenced to the Xian 1980 GK zone 19 coordinate system. The Scenario Cellular Automata models were set up using the scripts from the SLEUTH model under a UNIX operation system. The resulting images were reinserted back to the ArcMap conditions with specific scale and alignment to trace the original data ordinance and boundaries.

The manually input data were collected in Excel and the normalization process used the formula:

$$\boldsymbol{Normalized(ei)} = \frac{\mathbf{ln}(\boldsymbol{ei}) - \boldsymbol{E_{min}}}{\boldsymbol{E_{max}} - \boldsymbol{E_{min}}}$$

Where
Emin = the minimum value for variable E
Emax=the maximum value for variable E
If *Emax* is equal to *Emin* then Normalized (ei) is set to 0.5

4. Research methodology

a. Cellular Automata: modeling modifications and change of parameters

The SLEUTH model, as explained in an early chapter, is one type of Cellular Automata model, and runs with a series of parameters including slope, land use, excluded, urban, transportation, and hillshade. The data were processed and transferred to raster files in ArcGIS for reprocessing to provide workable files tailored for the SLEUTH model. What follows is an outline of some of the input parameters for the urban growth simulation. These also include ‘slope’ and ‘transportation’ characteristics. Generally, data entry was in the form of a pixelated mapped depiction, where pixels again correspond to cells in the Cellular Automata scheme. The spatial resolution, or scale, or each pixel (cell) is relatively small at one square kilometer (Rowe, 2013).

i. Slope

The slope was derived from a digital elevation model (DEM), where the elevation source data was extracted from CGIAR-I SRTM dataset downloaded from NASA. The derivation process applied a surface analysis function in ArcGIS.

Cell values must be in percent slope, not degree, which is a common default in some GIS software. Here, the input raster was the digital elevation model converted from satellite images, and the output raster was the slope map required for the Cellular Automata model. The output measurement was set to be percent rise, also referred to as percentage slope. The model was built within ArcMap catalog. It was calculated as:

$$S = \left(\frac{Ri}{Ru}\right) * 100$$

Where
P = Percentage of slope,
R = Rise,
Ri = Rise,
Ru = Run

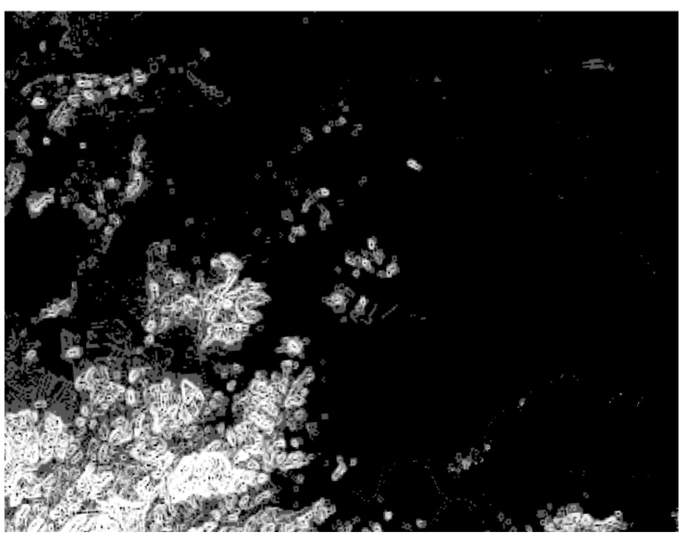


Figure 20. A slope image derived from DEM, original image was produced with 200dpi resolution, 2010.

Excessive slope of land discourages intensive land development and was regarded as unsuitable for urbanization. This speculation was backed by scholars from varies field of research. Kline stated that a variable specifically describing the slope of plots is desirable because land located at higher elevations may show reduced urban potential due to poor access or steep slopes (Kline, 2016). As a rule of thumb, contemporary land-use regulations prohibit building on land comprising slopes greater than forty percent. In the Cellular Automata model, a lower likelihood of urban conversion was set to assume lesser frequency of urbanization occurring on land with steeper slopes, relatively customary in China.

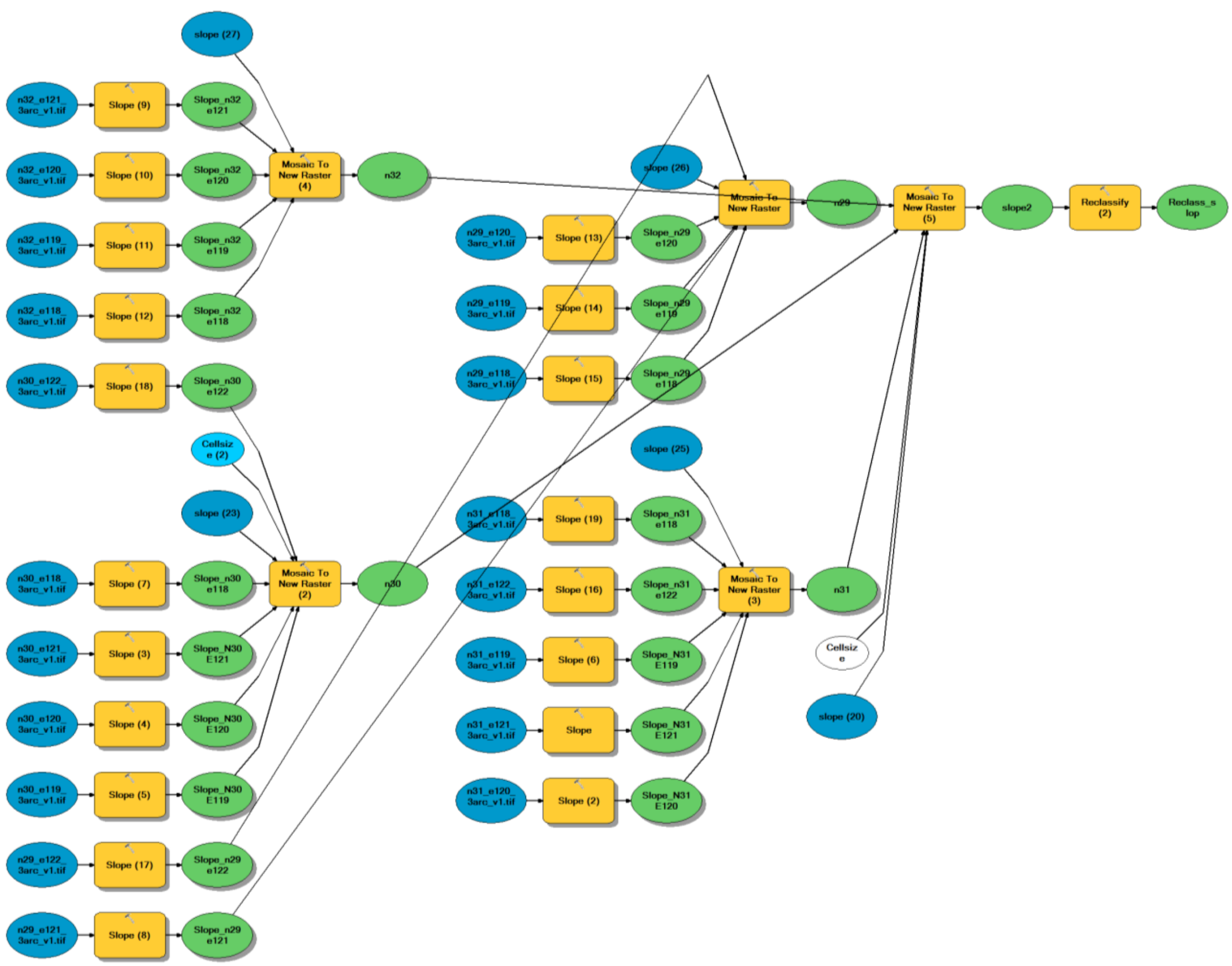


Figure 21. Slope raster model in ArcGIS.

ii. Land use

Land use images were produced in grayscales. Each pixel value contained in the grayscale land use images representing a unique land class. The following scheme was used to classify the land cover data: (R,G,B) class, (0,0,0) Water, (1,1,1) Urban/Road, (2,2,2) Agriculture, and (4,4,4) Forest.

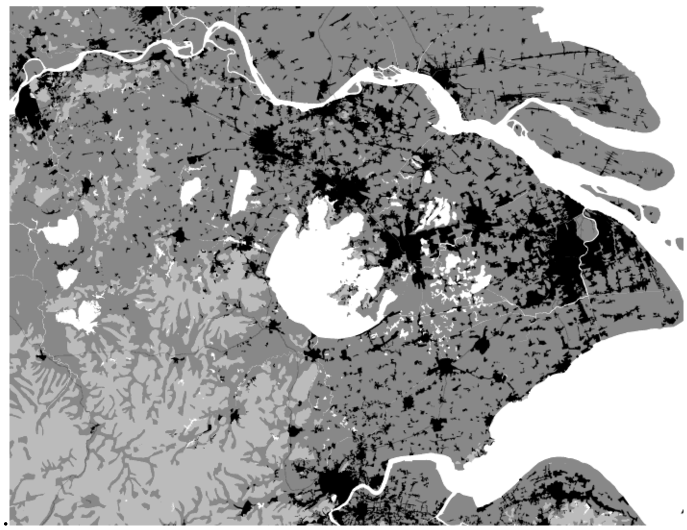


Figure 22. A land use image of the Changjiang Delta Region, derived from Landsat images classification using remote sensing technique, 2010.

Figure 23. Land use raster model in ArcGIS.

iii. Excluded

The excluded image defines all locations that are resistant to urbanization. Areas where urban development is considered impossible, such as open water bodies or national parks for example, are given a value of 100 or greater. Locations that are available for urban development have a value of zero (0).

Pixels may contain any value between (0-100) if the representation of partial exclusion of an area is desired - unprotected wetlands could be an example: Development is not likely, but there is no zoning to prevent it. Pixel value range: 0 - 255 (values > 100, are read as 100).

Figure 24. An excluded map of the Changjiang Delta Region, 2010.

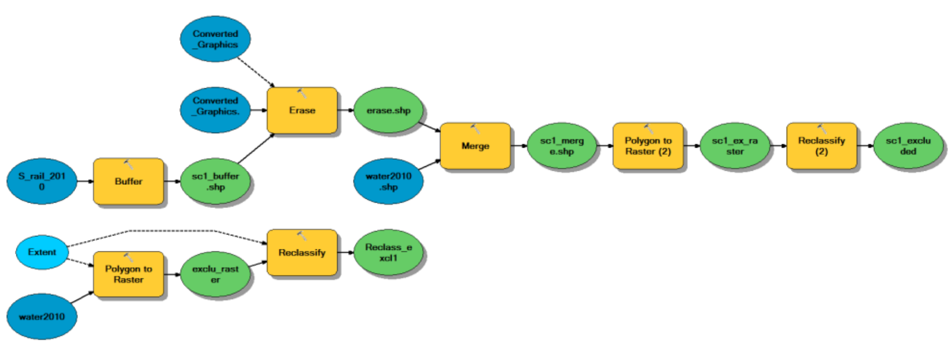


Figure 25. Excluded raster model in ArcGIS.

iv. Urban

The urban extent for the start year, or 'seed', is used to initialize the model and is the basis for the CA driven urban growth. For calibration, the earliest urban year is used as the seed, and subsequent urban layers, or control years, are used to measure several statistical best fit values. For this reason, at least four urban layers are needed for calibration: one for initialization and three additional layers for a least-squares calculation.

The definition of 'urban extent' is up to the initiators of the data set. The model simply requires a binary classification of urban/nonurban. Methods used in the past include digitizing city maps and aerial photographs, thresholding remotely sensed images, or block densities from census data.

Pixel value range: 0 = nonurban, 0 < n < 256 = urban.

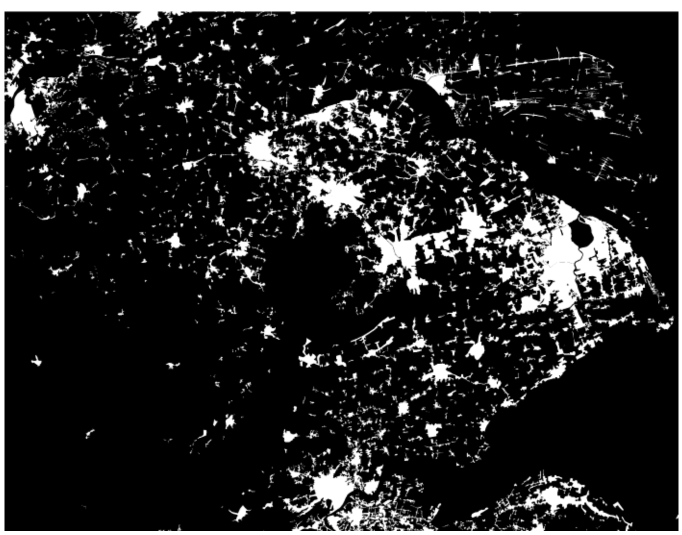


Figure 26. An urban image for the Changjiang Delta Region, 2010.

Figure 27. Urban raster model in ArcGIS.

v. Transportation

The road influenced growth dynamic included in SLEUTH simulates the tendency of urban development to be attracted to locations of increased accessibility. A transportation network can have major influence upon how a region develops. To include this effect in calibration several road layers, which change with the city's growth over time, are desirable. SLEUTH was initialized with the earliest road layer. As growth cycles, or "time", pass and the date for a more recent road layer is reached, the new layer was read in and development will proceeded from there. Road network images may be binary (road/non-road) or have relative values:

weighting 1	*weighting 2*	
pixel values	*pixel values*	*accessibility*
4	*100*	*high*
2	*50*	*medium*
1	*25*	*low*
0	*0*	*none*

Note that the relative weighting of the two schemes above are equivalent and would have an identical effect if applied to the same data. Pixel value range: binary: 0 = non-road, 0 < n < 256 = road.

Figure 28. A transportation map for the Changjiang Delta Region, 2010.

vi. Other parameters: Hillshade

Hillshade gives spatial context to the urban extent data, as a background image that was incorporated into image output.

To give further definition to a region, bodies of water may also be represented. This occurs by any pixels in the background image whose values are zero (0) being filled with the WATER color defined in the scenario file. Note this will also mean that any heavily shaded locations that have a zero value will also be filled with the WATER color. This can be avoided by remapping any zero values in the hillshade image to one (1) before adding the water mask.

If WATER is defined as black (R,G,B = 0,0,0) zero value pixels will remain black in the output images.

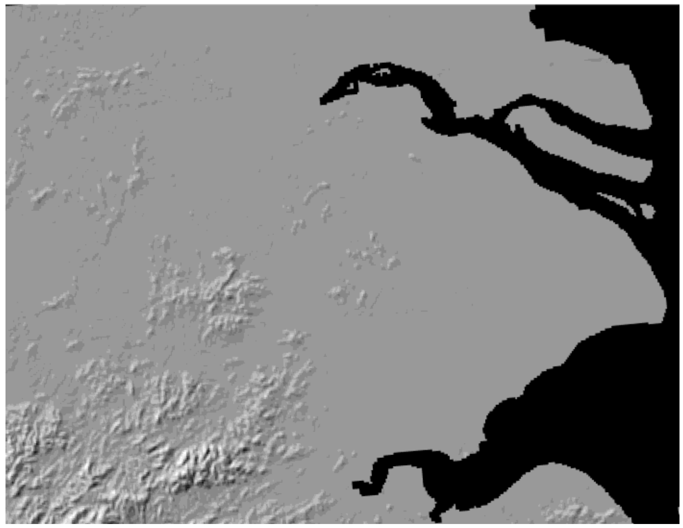


Figure 29. A hillshade map for the Changjiang Delta Region, 2010.

b. Modeling calibrations, Monte Carlo processes, and coefficients derivations

Model function verification

The verification process compiled a library for the modeling. It was conducted using a GNU/Linux system. The compiler's essential duty is to translate a computer program language to another, in this case, a machine code to a platform that supported the calibration process. The document produced after executing the command was a SLEUTH beta library. After which, a test run was executed where all calibration coefficients were set to start from 0 and end at 100 with a step of 25. It gave a five step verification process and drove a result of predicted best fit. The resulted ranges were less relevant but it prepared the model to be calibrated.

Model calibration

Due to the extensive computational requirements of calibrating the model, a brute force method[2] has been used to derive parameter values. This method involves calibrating the model to

[2] A brute force method, also known as proof by exhaustion, is a method of mathematical proof in which the statement to be proved is split into a finite number of cases or sets of equivalent cases and each type of case is checked to see if the proposition in question holds (Reid, D.A. and Knipping, C., 2010).

the data in steps, sequentially narrowing the range of coefficient values and increasing the data resolution.

The calibration process included three steps, a coarse calibration, a fine calibration, and a final calibration. In the initial coarse phase of calibration, the entire range (0 - 100) of the five coefficients is explored using large increments (e.g.; for each coefficient, value = {0, 25, 50, 75, 100}), and the resolution of the data is 1/4 of its full size.

Using the best fit values found in the control_stats.log file produced in the coarse calibration phase, the range of possible coefficient values is narrowed. Ideally, the ranges will be narrowed so that increments of 5 - 10 may be used while still only using about 5-6 values per coefficient (e.g.; for a coefficient, value = {25, 30, 35, 40, 45, 50}). These new ranges are then applied to data that has been resampled to 1/2 of its full resolution.

Using the best fit values found in the control_stats.log file produced in the fine calibration phase, the range of possible coefficient values is narrowed. Ideally, the ranges will be narrowed so that increments of 1 - 3 may be used while still only using about 5-6 values per coefficient (e.g.; for a coefficient, value = {4, 6, 8, 10, 12}). These new ranges were then applied to the full resolution data.

Coefficients derivation and Lee-Sallee metric

Geographers attempting to measure the shape of geographical objects have sought to eliminate subjective descriptions by creating a function that assigns unique numbers or sets of numbers to specific shapes, but such an assignment function is shown to be impossible. Therefore it is proposed here that the symmetric difference metric be used to compare the unknown shapes of geographical objects with easily described and visualized standards. For example, with the circle as standard, unknown shapes can be ranked according to their degree of circularity. Circularity, in turn, corresponds to relative compactness. By using several different geometric shapes as standards, the geographer can examine landscape features to determine which standard best describes their shapes (Lee & Sallee, 1970). The equation was adopted and revised from the original Lee-Sallee Metric (LSM):

$$LS = 1 - \left[area \frac{(Sp \ \cap Ss)}{(Sp \ \cup Ss)} \right]$$

Where,

LS = the Lee-Sallee Metric
Sp = the predicted shape
Ss = the standard shape

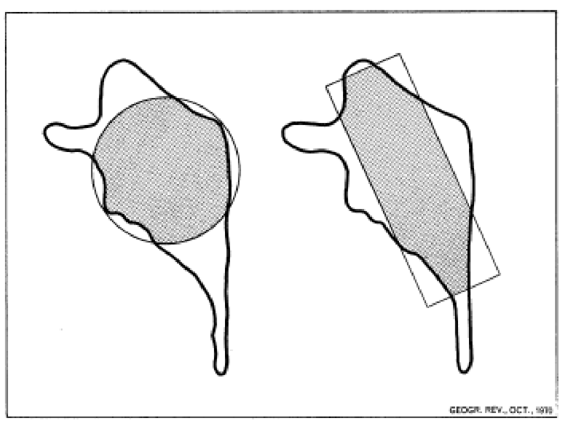


Figure 30. Village shape compared with the circle and the rectangle.

The limitation of the LSM was the ignorance of local conditions, for example, topography. Based on the Lee-Sallee Metric, a town-shape metric was developed (*St*), it alternated the measurement of standard shape in the Lee-Sallee Metric and established a system that better described the local conditions. The research on (*St*) is out of the scope of this dissertation but is set aside for future related research.

Monte Carlo Iteration

Computational algorithms that are most useful when it is difficult or impossible to use other mathematical methods deploy so-called Monte Carlo Iteration. They rely on repeated random sampling to obtain numerical results. Regarding Cellular Automata, the method was invented by Stanislaw Ulam and then developed and programmed by John von Neumann at Los Alamos Scientific Laboratory when they were working on nuclear weapons. Though the pseudorandom number and middle-square inherited with the method contained weakness and was regarded as crude, it was justified as being faster than other methods and was applied to the Manhattan Project. In 1990s, Sequential Monte Carlo and Bayesian inference was used to improve the calculation algorithm to be more heuristic-like and natural. Now the method has a much wider application. Through a simulation program such as Cellular Automata, the method was also adopted to predict potential future urbanization patterns (Eckhardt, 1987). The equation that represents how a random location was picked is the following:

$$F = \sum_{i=1}^{n} f(xi)/N$$

Where,

F is the average cells picked
N is the total number of cells
Xi is a random cell
f(xi) is the function of the average of the quantity

c. Scenario modeling

Scenario modeling was developed based on the algorithm of Cellular Automata model and using the scripts from the SLEUTH model, with additional variables that guide and control the growth pattern. The modification of parameters did not change how the principles of the Cellular Automata model operate. However, they did provide opportunities to reflect the influences of certain urban policies on the outcome of the urban land growth patterns predictions.

i. Development corridor

As mentioned in the previous sections, development corridors shape the basic spatial economic structure of the Changjiang Delta region. The scenario model was modified to reflect the impact of the existence of these development corridors. A new variable, G-corridor, was added to the formula, thus, the urban growth prediction model became:

$$\boldsymbol{G_{total}^{t+1}} = \sum \boldsymbol{G_{spontaneous(i,j)}^{t+1}} + \boldsymbol{G_{spread(i,j)}^{t+1}} + \boldsymbol{G_{edge(i,j)}^{t+1}} + \boldsymbol{G_{road(i,j)}^{t+1}} + \boldsymbol{G_{corridor(i,j)}^{t+1}}$$

Where,

$\boldsymbol{G_{total}^{t+1}}$= Total urban growth prediction, at year t+1

$\boldsymbol{G_{spontaneous(i,j)}^{t+1}}$ = Spontaneous growth, the occurrence of random urbanization of land, at year t+1

$\boldsymbol{G_{spread(i,j)}^{t+1}}$ = Spread growth, the urban spreading of newly urbanized land cell, at year t+1 (pay attention that this excluded the spread growth of existing urbanized land cell)

$\boldsymbol{G_{edge(i,j)}^{t+1}}$ = Edge growth, the further expansion of newly spread urbanized cell, at year t+1

$\boldsymbol{G_{road(i,j)}^{t+1}}$ = Road influenced growth, at year t+1

$\boldsymbol{G^{t+1}_{corridor(i,j)}}$ = Development corridor growth, at year t+1

Within this model, each growth types were further explained with the following formulas:

$$\boldsymbol{G^{t+1}_{spontaneous(i,j)} = f[\, Dis^{t}_{(i,j)}, Slo^{t}_{(i,j)}\,]}$$

Where,

$\boldsymbol{G^{t+1}_{spontaneous(i,j)}}$ = The occurrence of random urbanization of land, at year t+1

$\boldsymbol{Dis^{t}_{(i,j)}}$ = Dispersion coefficient, at year t

$\boldsymbol{Slo^{t}_{(i,j)}}$ **=** A percent slope at which urbanization is impossible, at year t

$$\boldsymbol{G^{t+1}_{spread(i,j)} = f[\, Bre^{t}_{(i,j)}\,]}$$

Where,

$\boldsymbol{G^{t+1}_{spread(i,j)}}$ = the urban spreading of newly urbanized land cell, at year t+1

$\boldsymbol{Bre^{t}_{(i,j)}}$ = bread coefficient, at year t

$$\boldsymbol{G^{t+1}_{edge(i,j)} = f[\, Spr^{t}_{(i,j)}, Slo^{t}_{(i,j)}, Nei^{t}_{(k,l)}\,]}$$

Where,

$\boldsymbol{G^{t+1}_{edge(i,j)}}$ = The further expansion of newly spread urbanized cell, at year t+1

$\boldsymbol{Spr^{t}_{(i,j)}}$ **=** Spread coefficient, at year t

$\boldsymbol{Slo^{t}_{(i,j)}}$ = A percent slope at which urbanization is impossible, at year t

$\boldsymbol{Nei^{t}_{(k,l)}}$ = Neighborhood urbanized condition, at year t

$$G_{road(i,j)}^{t+1} = f[\ Roa_{(i,j)}^{t}, Exi_{(m,n)}^{t}\ ]$$

Where,

$G_{road(i,j)}^{t+1}$ = Road influenced growth, at year t+1

$Roa_{(i,j)}^{t}$ = Road gravity coefficient, at year t

$Exi_{(m,n)}^{t}$ = Existing road, urbanized grid cell or not, at year t

$$G_{corridor(i,j)}^{t+1} = f[\ Cor_{(i,j)}^{t}\ ]$$

Where,

$G_{corridor(i,j)}^{t+1}$ = Development corridor growth, at year t+1

$Cor_{(i,j)}^{t}$ = Development corridor growth coefficient, at year t

ii. Development corridors, plus big city growth

In this model, the big cities enjoy a similar growth opportunity as the development corridors. The growth priority was given to the development corridors if conflicts were to occur between gird cells of the development corridors and the big cities. The scenario model was modified to reflect the continuing growth of big cities. A new variable, G-city, was added to the formula, thus, the urban growth prediction model became:

$$G_{total}^{t+1} = \sum G_{spontaneous(i,j)}^{t+1} + G_{spread(i,j)}^{t+1} + G_{edge(i,j)}^{t+1} + G_{road(i,j)}^{t+1} + G_{corridor(i,j)}^{t+1} + G_{city(i,j)}^{t+1}$$

Where,

G_{total}^{t+1}= Total urban growth prediction, at year t+1

$\boldsymbol{G^{t+1}_{spontaneous(i,j)}}$ = Spontaneous growth, the occurrence of random urbanization of land, at year t+1

$\boldsymbol{G^{t+1}_{spread(i,j)}}$ = Spread growth, the urban spreading of newly urbanized land cell, at year t+1 (pay attention that this excluded the spread growth of existing urbanized land cell)

$\boldsymbol{G^{t+1}_{edge(i,j)}}$ = Edge growth, the further expansion of newly spread urbanized cell, at year t+1

$\boldsymbol{G^{t+1}_{road(i,j)}}$ = Road influenced growth, at year t+1

$\boldsymbol{G^{t+1}_{corridor(i,j)}}$ = Development corridor growth, at year t+1

$\boldsymbol{G^{t+1}_{city(i,j)}}$ = Big cities growth, at year t+1

Within this model, the 'big cities growth' variable was further explained with the following formula:

$$\boldsymbol{G^{t+1}_{city(i,j)} = f[\, Cit^{t}_{(i,j)}, Cat^{t}_{(i,j)} \,]}$$

Where,

$\boldsymbol{G^{t+1}_{city(i,j)}}$ = Big cities growth, at year t+1

$\boldsymbol{Cit^{t}_{(i,j)}}$ = Big cities growth coefficient, at year t

$\boldsymbol{Cat^{t}_{(i,j)}}$ = Big cities category coefficient, at year t

The big cities category coefficient was used to define the rate of growth of each individual city or city category. This applied to situations when big cities grow with different rates.

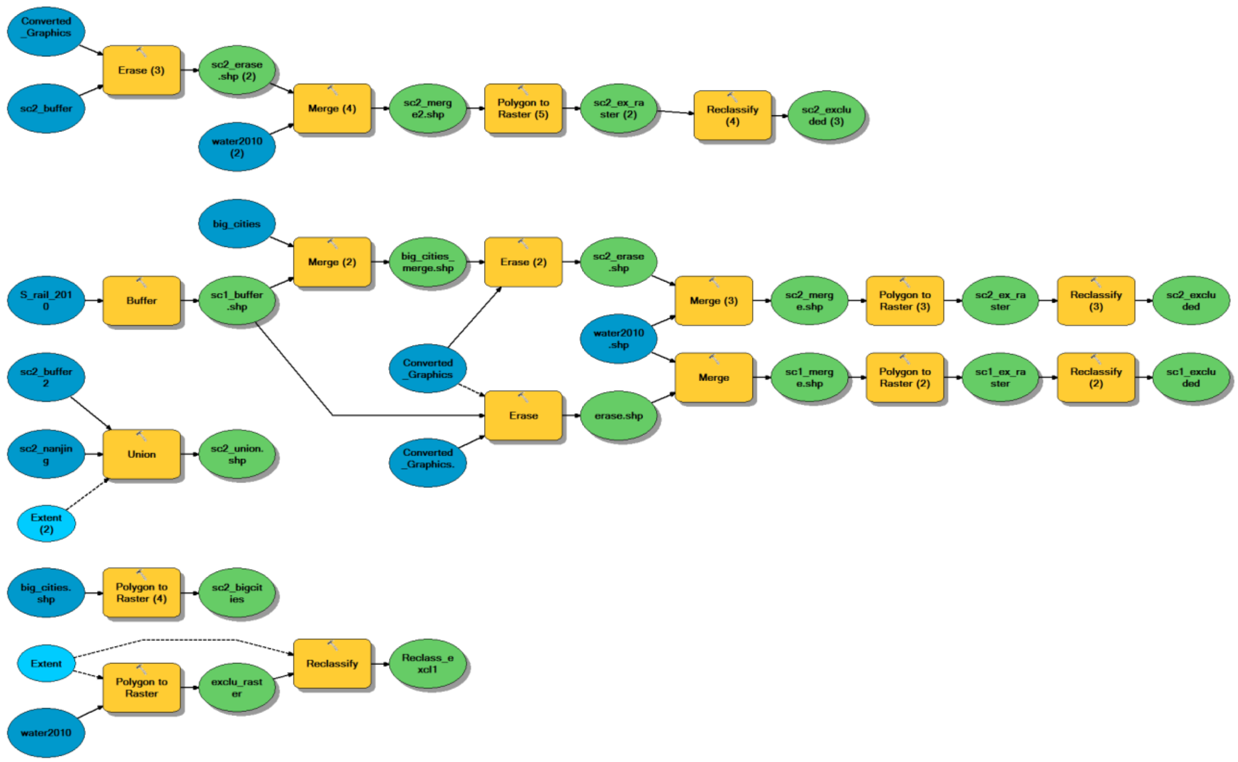


Figure 31. Big city growth variable deriving model in ArcMap.

iii. Ecological system concerns (e.g. forest protection), plus development corridors

In this model, representation of ecological systems, i.e., forest protection, obtained priority over development corridors. If conflicts were to occur between the two, the development corridors were reduced to zero, meaning no future growth was allowed. For this variable, forest protection can be replaced by other research concerns, flooding, and arable land, for example, to address other ecological issues. The scenario model was modified to reflect the ecological system concerns. A new variable, ***Gecol***, was added to the formula, thus, the urban growth prediction model became:

$$G_{total}^{t+1} = \sum G_{spontaneous(i,j)}^{t+1} + G_{spread(i,j)}^{t+1} + G_{edge(i,j)}^{t+1} + G_{road(i,j)}^{t+1} + G_{corridor(i,j)}^{t+1} + G_{ecological(i,j)}^{t+1}$$

Where,

G_{total}^{t+1}= Total urban growth prediction, at year t+1

$G_{spontaneous(i,j)}^{t+1}$ = Spontaneous growth, the occurrence of random urbanization of land, at year t+1

$G_{spread(i,j)}^{t+1}$ = Spread growth, the urban spreading of newly urbanized land cell, at year t+1 (pay attention that this excluded the spread growth of existing urbanized land cell)

$G_{edge(i,j)}^{t+1}$ = Edge growth, the further expansion of newly spread urbanized cell, at year t+1

$G_{road(i,j)}^{t+1}$ = Road influenced growth, at year t+1

$G_{corridor(i,j)}^{t+1}$ = Development corridor growth, at year t+1

$G_{ecological(i,j)}^{t+1}$ = Ecological system concerns, at year t+1

Within this model, the 'ecological system concerns' variable was further explained with the following formula:

$$G_{ecological(i,j)}^{t+1} = f[\, Eco_{(i,j)}^{t}, Oth_{(i,j)}^{t} \,]$$

Where,

$G_{ecological(i,j)}^{t+1}$ = Ecological system concerns, at year t+1

$Eco_{(i,j)}^{t}$ = Ecological system (forest protection) coefficient, at year t

$Oth_{(i,j)}^{t}$ = Other ecological system concerns, at year t

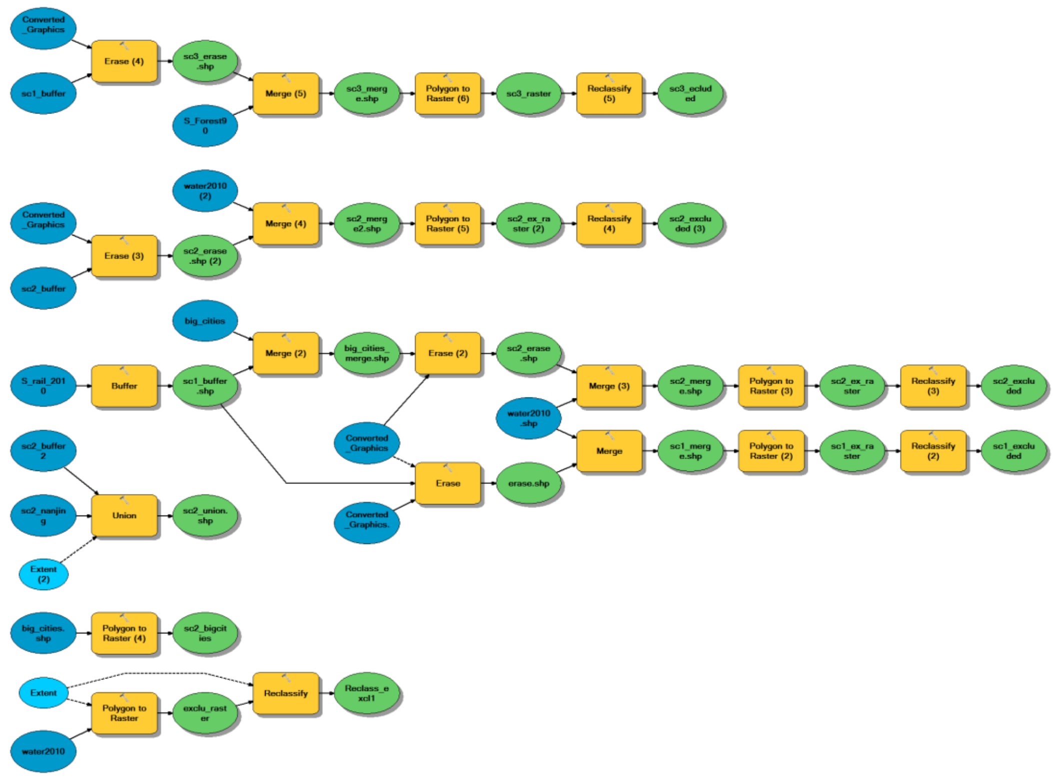


Figure 32. Ecological system concerns variable derivation model in ArcMap.

iv. Disaster prevention, plus development corridors

In this model, disaster prevention, obtained priority over development corridors. If conflicts were to occur between the two coefficients, the coefficient for the development corridors were reduced to zero, meaning no future growth allowed. The scenario model was modified to reflect conditions of disaster prevention. A new variable, ***Gdisa***, was added to the formula, thus, the urban growth prediction model became:

$$\boldsymbol{G_{total}^{t+1}} = \sum \boldsymbol{G_{spontaneous(i,j)}^{t+1}} + \boldsymbol{G_{spread(i,j)}^{t+1}} + \boldsymbol{G_{edge(i,j)}^{t+1}} + \boldsymbol{G_{road(i,j)}^{t+1}} + \boldsymbol{G_{corridor(i,j)}^{t+1}} + \boldsymbol{G_{disaster(i,j)}^{t+1}}$$

Where,

$\boldsymbol{G_{total}^{t+1}}$= Total urban growth prediction, at year t+1

$\boldsymbol{G_{spontaneous(i,j)}^{t+1}}$ = Spontaneous growth, the occurrence of random urbanization of land, at year t+1

$\boldsymbol{G_{spread(i,j)}^{t+1}}$ = Spread growth, the urban spreading of newly urbanized land cell, at year t+1 (pay attention that this excluded the spread growth of existing urbanized land cell)

$\boldsymbol{G_{edge(i,j)}^{t+1}}$ = Edge growth, the further expansion of newly spread urbanized cell, at year t+1

$\boldsymbol{G_{road(i,j)}^{t+1}}$ = Road influenced growth, at year t+1

$\boldsymbol{G_{corridor(i,j)}^{t+1}}$ = Development corridor growth, at year t+1

$\boldsymbol{G_{disaster(i,j)}^{t+1}}$ = Disaster preventions growth, at year t+1

Within this model, the 'Disaster preventions growth' variable was further explained with the following formula:

$$\boldsymbol{G_{disaster(i,j)}^{t+1} = f[\, Dis_{(i,j)}^{t} \,]}$$

Where,

$\boldsymbol{G_{disaster(i,j)}^{t+1}}$ = Disaster preventions growth, at year t+1

$\boldsymbol{Dis_{(i,j)}^{t}}$ = Disaster preventions, at year t

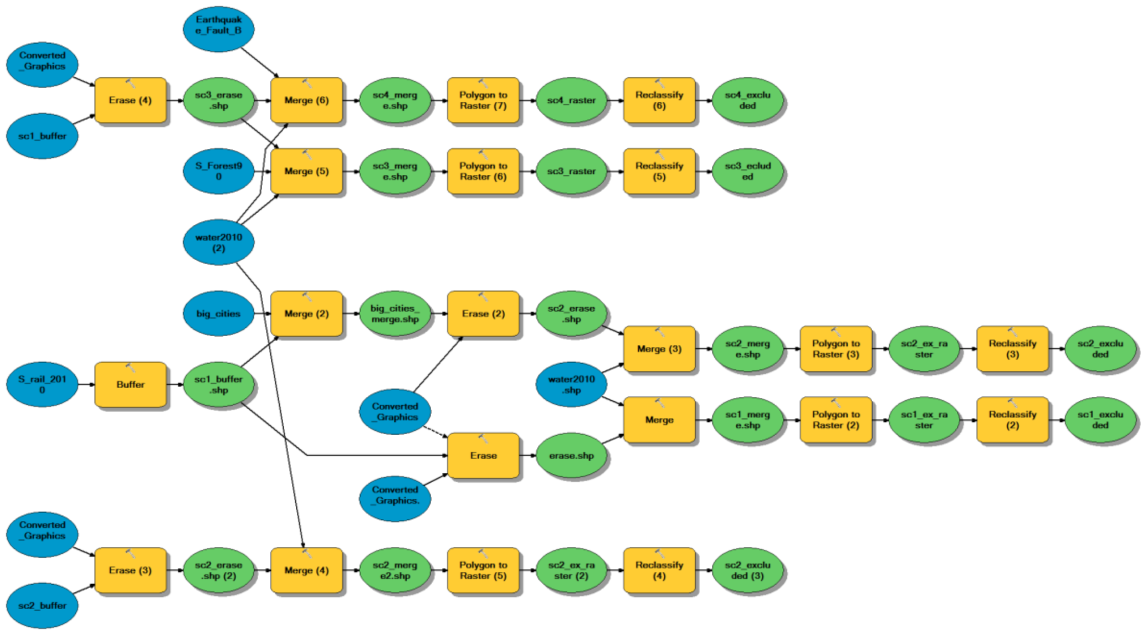


Figure 33. Disaster prevention variable derivation model in ArcMap.

d. Baseline modeling: descriptions of three baselines by administrative districts

Three baselines were created by administrative districts to compare with the scenario-based predictions. They were environmental suitability, economic performance, and cultural amenity. Two additional baselines were compactness of urban form and shape of urban form. However, both were left out of scope of this dissertation because it required the application of town-shape metric that is yet to be fully developed. Effectively, it was set aside for future related research together with the town-shape metric.

i. Baseline 1: environmental suitability

The purpose of this exercise was to find suitable areas for urban development and to identify areas that are most vulnerable from human interference. It involved identifying criteria that define environmental suitability. Previous studies ranged in degree of computational and analytical sophistication included pass/fail screening, weighted factors, penalty point assignment, and composite rating (Banai-Kashani, 1987). More recent studies, built on earlier methods, included the 'weighted linear combination' method and the 'analytic hierarchy process'. The former accommodated more parameters and the latter dealt with both intangible and tangible factors, however, it required a limited number of factors.

In this research, a combined approach of 'weighted linear combination' and 'analytic hierarchy process' was employed. It was a multi-criteria evaluation and decision making process. First, the criteria were selected for this research, including landslides, earthquake, floods, sea-level rise, slope of land, land cover and resources, land subsidence, proximity to drinking water resources, and view shed, . The criteria were mapped and georeferenced to ArcGIS and converted to raster files.

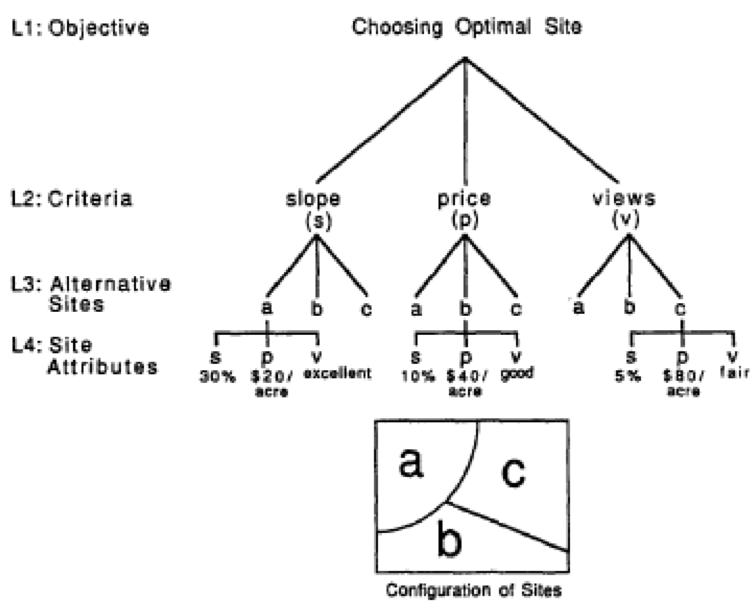


Figure 34. Analytic Hierarchy Process for suitability study.

The trade-off among criteria considered the level of correlation that existed in a set of selections. If two variables were highly correlated with each other, for example, sea-level rise and distance to the ocean, one of them was dropped, or both were given a reduced weight.

It was critical to recognize what were more important than others. Assuming criteria were equally important then the weighting should all be 1.0. However, such an outcome depends on the influence of each criterion. Some were always given more weight than others. The weighting was realized by 'weighted overlay' in ArcGIS.

The next step was to combine the weighted datasets, for both quantitative and qualitative criteria. A normalization process was applied to summarize all criteria to one single index. This function was realized in ArcMap using the command 'sum' after normalization. The equation was listed as follow and the modeling structure and variables selected for environmental suitability were in Figure 35.

$$ES = \sum_{i=1}^{n} f(xi * wi)$$

Where,

ES is the environmental suitability index
f is a normalization function
Xi is the criterion selected
Wi is the weighting for each criterion
n is the total number of criteria

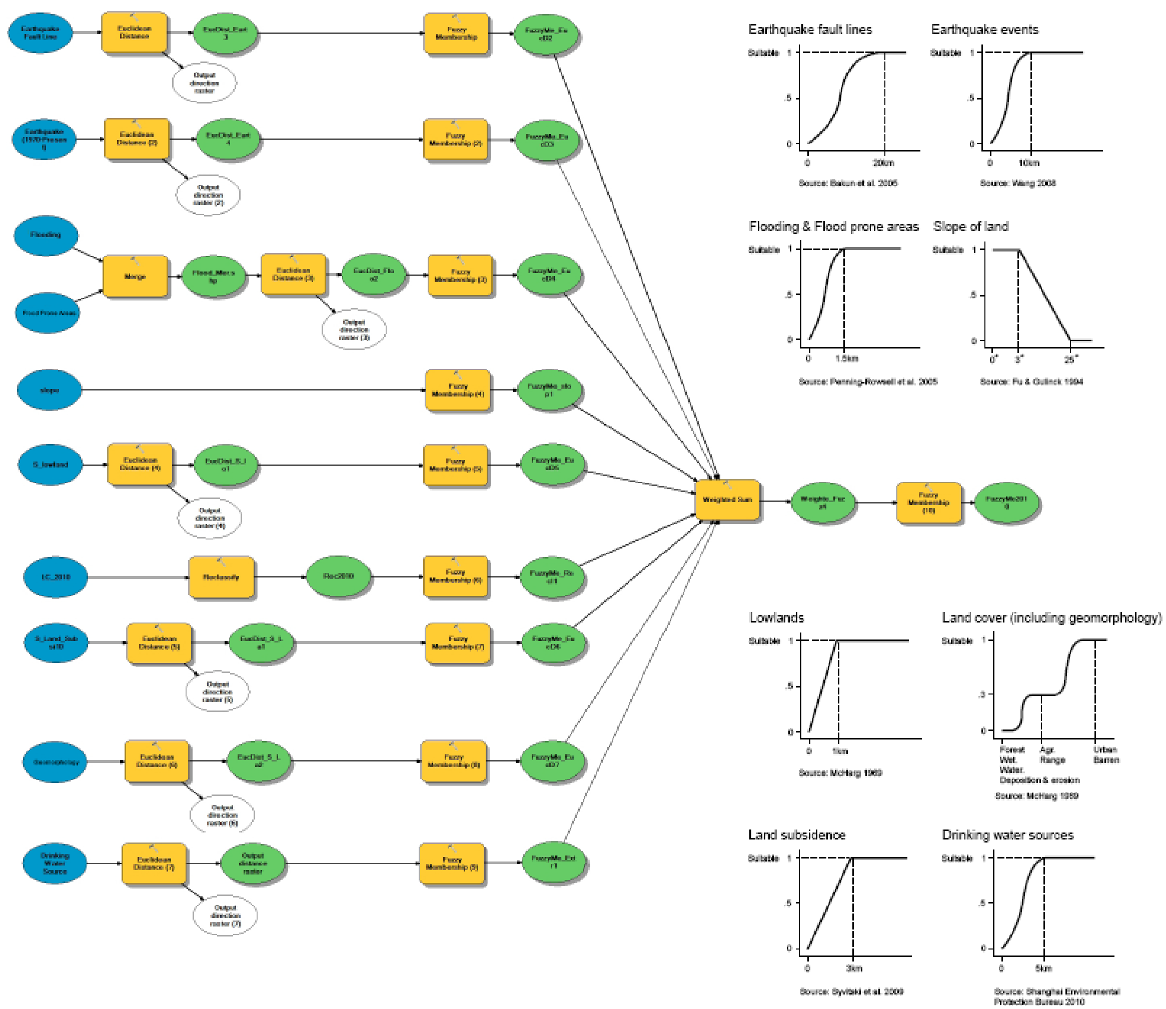


Figure 35. Environmental suitability analysis.

ii. Baseline 2: economic performance

To measure economic performance, there are many factors such as purchasing power, levels of savings and savings ratios, price level and inflation, trade deficits and surpluses, growth in real national income, among others. There are also readily established indexes, such as the Human Development Index (HDI) which measures literacy rates and health care provision, and the Human Poverty Index (HPI) which measures of human poverty. Other theories particularly emphasize the potential for innovation and knowledge spillovers and the composition of economic activity (Glaeser et al., 1992, Fujita et al., 1999, Delgado et al, 2014).

For this research purpose, the focus was on how economic performance of current administrative land areas can be associated with predicted urban growth. Here, economic performance was represented by both growth potential and current economic conditions. They were measured by intrinsic conditions and relevant conditions. In this exercise, the intrinsic conditions referred to those within the administrative boundaries, and the relevant conditions referred to those measured with regard to neighboring cities and towns. The selection of intrinsic variables was challenging because many of the indices were correlated and data collection at the city and town level was also problematic and often encountered issues, such as data inconsistency. The strategy was to include the most representative variables that represent productivity, investment, and revenue. There are many variables measuring productivity, among them the Gross Domestic Product (GDP) is the most commonly used. GDP per capita or GDP per square kilometers was the most recognizable proxy for production. In this research, data on GDP from 2010 were selected as the baseline for economic performance. The numbers were acquired from China Statistical Yearbook 2011, Provincial Statistical Yearbooks 2011, as well as some city level statistical yearbooks.

On the investment side, national fixed asset investment in urban service facilities was selected. It included financial allocation from the central government budget, financial allocation from the local government budget, domestic loans, securities, foreign investments and foreign direct investments, and self-raised funds and self-owned funds. However, it didn't cover the urban public transport facilities. This list of variables provided a relatively comprehensive measurement of urban fixed asset investment. On the revenue side, the revenue of urban maintenance was selected. It included urban maintenance and construction tax, extra-charges for municipal utilities, fees for expansion of municipal utilities capacity, fees for use of municipal utilities, tolls on roads and bridges, water treatment fees, garbage treatment fees, land transfer revenues, water resource fees, and revenues. This list, in effect, was composed of almost all of the major revenues associated with urban maintenance. The data was collected from the China Urban Construction Statistical Yearbook 2011, the Zhejiang Province Statistical Yearbook 2011, the Jiangsu Province Statistical Yearbook 2011, the Shanghai Statistical Yearbook 2011, and other supplementary city and township level yearbooks and related materials.

Road access or road length per capita was considered to be one of the variables but was dropped from the equation as the category of road and conditions were hard to evaluate. For those areas lacking in information, data was used from one level up the administrative hierarchy to fill in the blank.

The three variables describing intrinsic conditions of urban economic performance, GDP per capita, national fixed asset investment, and urban maintenance revenue were consolidated into an 'economic performance index', using 'weighted linear combination' method. The equation used was as follows:

$$EP = \sum_{i=1}^{n} f(yi * wi)$$

Where,
EP is the economic performance index for intrinsic variables
f is a normalization function
yi is the criterion selected
wi is the weighting for each criterion
n is the total number of criteria

To measure relevant conditions of economic performance, a method called Univariate Moran's I was applied. Moran's I is an indication of the relationship between a vector of observed values, x, here representing variables concerned urban growth prediction, and a weighted average of values that are contiguous to x. The latter are often referred to as the 'spatial lag of x', and are expressed as lagged x, where 'lagged' stands for the average value of neighbors as defined by the weight matrix. The calculated value of Moran's I is the slope coefficient of a regression of 'lagged x on x'. The function was realized in Exploratory Spatial Data Analysis, using Univariate Moran's I under space command. The variable was standardized and the graph was divided in to four quadrants: high-high (upper right) and low-low (lower left) for positive spatial autocorrelation; and high-low (lower right) and low-high (upper left) for negative spatial autocorrelation. The slope of the regression line is Moran's I (based on queen's contiguity). Then a correlation between lag conditions of economic performance and urban growth prediction was made. A high urban growth prediction in high-high quadrant often reveals continuing growth of exiting urban clusters and the low-low quadrant reveals the formation of new towns and emerging urban concentration.

The growth potential was predicted based on the Scenario Cellular Automata model, which is independent of the economic conditions. A scatter plot was created where x axis represents current economic conditions of the cities and y axis represents their urban growth potential. Further, a high-low distribution analysis was performed. A method called bivariate Local Moran's I statistics was applied. The two variables chosen here also predicted urban growth by grid cells from the Scenario Cellular Automata model and economic performance.

iii. Cultural amenity

Historical inner cities and cultural relics of outer cities often provide a special identity to the urban region and its constituent areas and were considered important factors to attract residents and encourage future urban growth. From bottom-up consideration of urban dweller's choice making, the measure of culture amenity was associated with the willingness to pay for cultural heritage locations. The hedonic price method linked house prices to the presence of cultural heritage in the vicinity and interprets its marginal prices as an indicator for the average willingness to pay for this amenity (Duijn & Rouwendal, 2013). On the other hand, the top-down decision making would concentrate on both material and immaterial conditions. The material conditions in this research included recreational space, scenic spots, number of parks, and the area of parks. The immaterial conditions included cultural heritage and tourist destinations, both of which have something to do with the images of the city or town process and impressions outsiders might hold. It could be ephemeral or permanent in comparison to the time scale of study period. The number of universities was excluded from the study, as it was considered as an independent measure of human capital investment and the historical and cultural heritage of modern universities in China were not quite imbedded in other local cultures that goes back a longer period in time. The data were collected from Harvard University online library and Yenching Library for these factors.

The study was based on administrative boundaries of cites. There were 62 cities located in the region, as discussed in the earlier chapters. The collected data were summarized in a table. The formula to evaluate cultural amenity was the follow:

$$CU = \sum_{i=1}^{n} f(zi * wi)$$

Where,

CU is the cultural amenity index
f is a normalization function
zi is the criterion selected, including, scenic spots, recreational space, number of parks, park area, and tourist destination
wi is the weighting for each criterion
n is the total number of criteria

The variables and proxies applied were also limited by data availability. It is challenging to undertake the task quantifying the culture as it in many ways reflects qualitative aspects of urban experiences.

e. Modeling structure: evaluations of the selected scenarios using baselines for comparisons and measurements

The results from the baseline conditions were used to measure against different scenarios of urban growth prediction. The three baselines, as stated earlier, were: environmental suitability, economic performance, and cultural amenity. The results from the urban growth prediction scenarios, also mentioned earlier, included: development corridors, development corridors plus big city growth, ecological system concerns (e.g., forest protection) plus development corridors, and disaster prevention plus development corridors. The comparisons and evaluations thus comprised twelve pairs as follows: environmental suitability vs. development corridors; environmental suitability vs. development corridors, plus big city growth; environmental suitability vs. ecological system concerns, plus development corridors; environmental suitability vs. disaster prevention, plus development corridors; economic performance vs. development corridors; economic performance vs. development corridors, plus big city growth; economic performance vs. ecological system concerns, plus development corridors; economic performance vs. disaster prevention, plus development corridors; cultural amenity vs. development corridors; cultural amenity vs. development corridors, plus big city growth; cultural amenity vs. ecological system concerns, plus development corridors; cultural amenity vs. disaster prevention, plus development corridors (Figure 36).

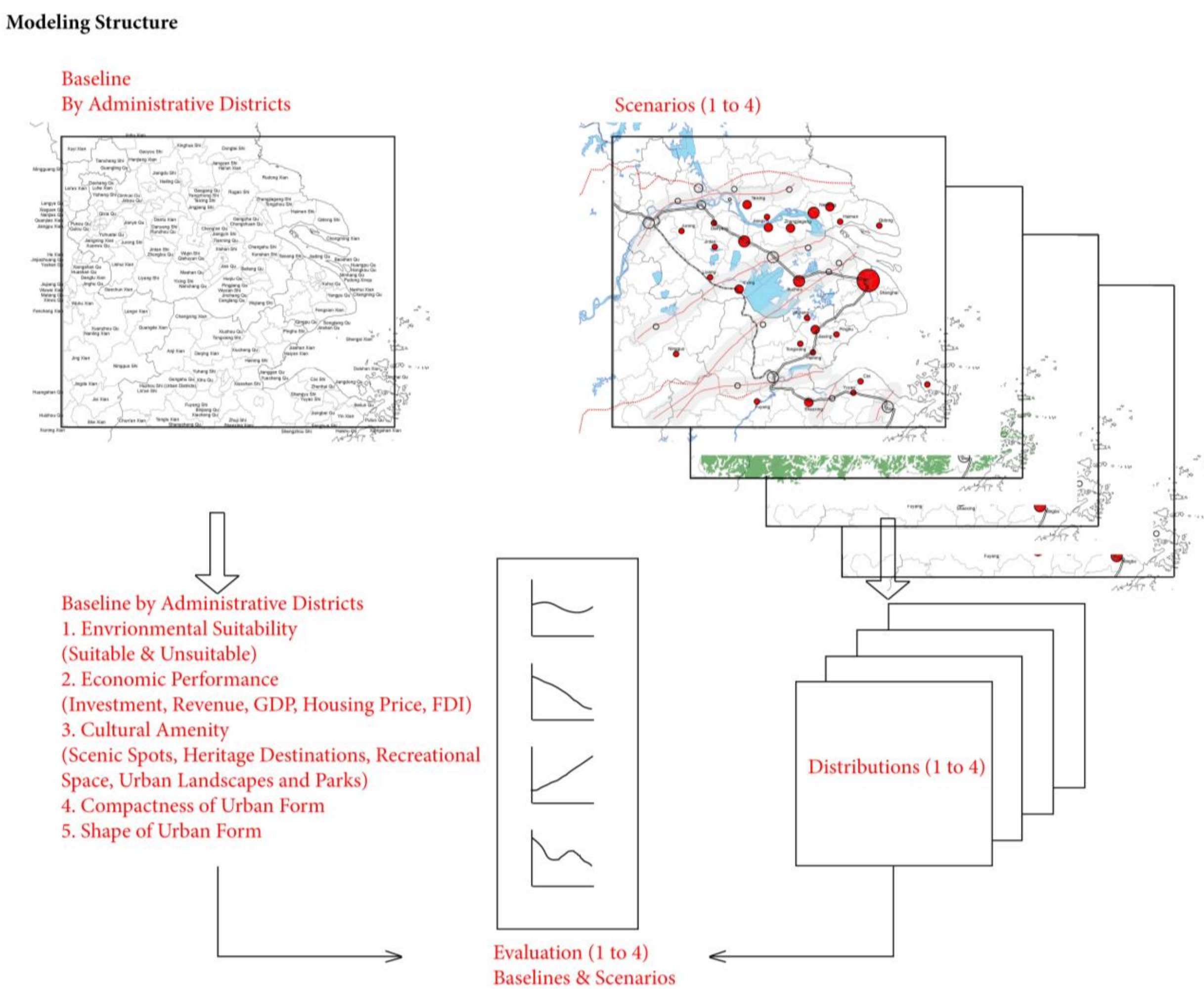


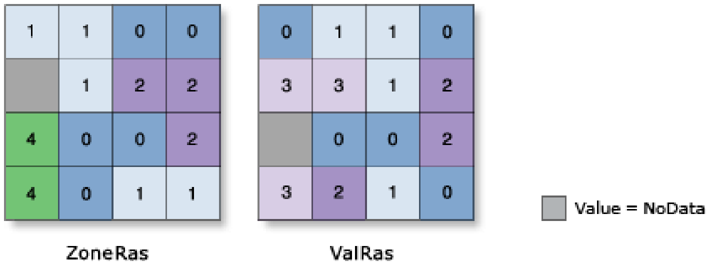
Figure 36. Modeling structure.

i. Urban growth scenarios and environmental suitability

An ArcGIS file was created with the same coordinate system of map projection. The results from the environmental suitability were imported to the file. An ArcGIS, reclassification was performed on the projected images so that they contained only two categories: urban with a value of 1 and non-urban with a value of 0. The same reclassification process was performed on suitability rasters as well, the resulting rasters contained only two categories: unsuitable with a value of 1 and suitable with a value of 0. The next step was using ‘Times’, a command that multiples the values of two rasters on a cell-by-cell basis. To be able to specify a number for both inputs, the cell size and extent were first set in the environment. The resulting rasters also contained only two values: urbanization in unsuitable area with a value of 1, the rest was an area with a value of 0. The intersection of ‘urban’ and ‘unsuitable’, the two key characteristics, was used to define a new set of rasters.

ii. Urban growth scenarios and economic performance

Similar to the above, an ArcGIS file was created with the same coordinate system of map projection. The results from the economic performance were imported to the file. In ArcGIS, using ‘zonal statistics’ with ‘input raster or feature zone data’ as the town boundary polygon and input value raster as the raster urban growth area. The output of this tool would be a raster with a field named ‘count’, that's the number of pixels need. However, the ‘zonal statistics’ didn’t provide a readily available table to summarize the pixels. ‘Zonal statistics as table’, under the spatial analysis toolbox was applied. It summarized the values of a raster within the zones of another dataset and reported the results to a table. First, the shapefiles of the county boundaries were converted to graphic form and then reconverted back to shapefiles under the same coordinate system. Then the statistical type was set to ‘all’. In the output table, the row of ‘sum’ contained the values and they were equal to the number of urbanized pixels.



=

Rowid	VALUE	COUNT	AREA	MIN	MAX	RANGE	MEAN	STD	SUM	VARIETY	MAJORITY	MINORITY	MEDIAN
1	0	5	5	0	2	2	0.6	0.8	3	3	0	1	0
2	1	5	5	0	3	3	1	1.095	5	3	0	3	1
3	2	3	3	1	2	1	1.667	0.471	5	2	2	1	2
4	4	1	1	3	3	0	3	0	3	1	3	3	3

Figure 37. Illustration of calculation algorithm of 'zonal statistics as table'. Source: Reproduced from Esri, 2015.

iii. Urban growth scenarios and cultural amenity

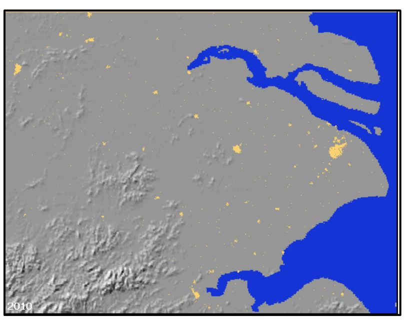
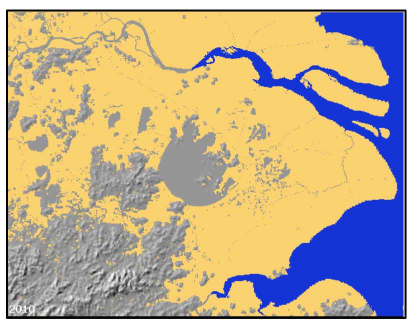
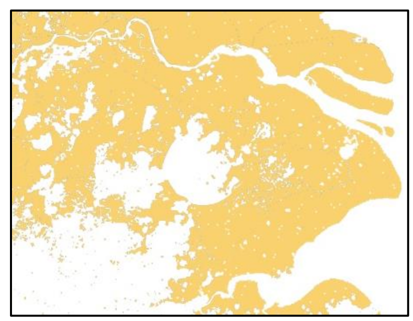
Also as in the above steps, an ArcGIS file was created with the same coordinate system of map projection. The results from the cultural amenity were imported to the file. The annually urban growth predictions from 2011 to 2030 were also imported to the file. In ArcGIS, 'zonal statistics' was applied and the steps were similar to urban growth scenarios and economic performance.

5. Results

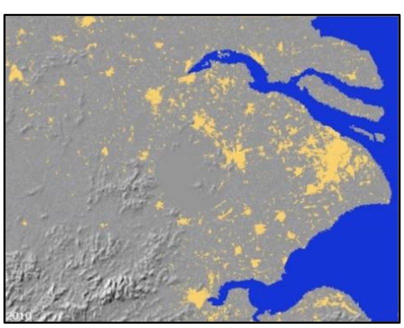
a. A Cellular Automata model for prediction of urban growth

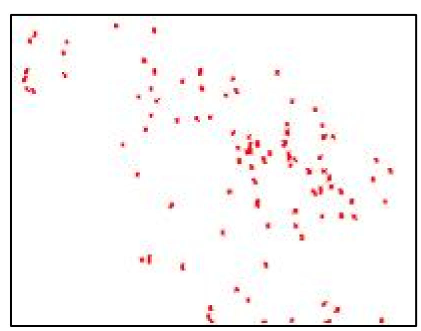
i. Test run

The test run provided the following results: either under-prediction or over-prediction. The under-prediction had a start value of zero. The start value determines the speed and intensity of urban conversion process. Thus a value of zero basically prevents all possible growth. The results revealed a static state of urban condition in 1950, which was the starting year of testing data. The over-prediction, on the other hand, increases the urban conversion process dramatically. The result was based on a value of 50. The urban conversion was observed to the extent that it covered most of the land area of the study region except those designated as excluded. By repeating the test run a few times, the re-adjusted start value was set to be fifteen. The two images, lower left and lower right in Figure 38, revealed that the predicted urban condition was comparable to the actual urban area in year 2010. The coefficient value ranged from 0 to 100 in the entire test runs. If more growth was desired, the coefficient start value should be increased and vice versa. The difference showed in Figure 38 was less than five percent. The red dots were enlarged for clarity to represent clusters of dissimilarity between re-adjusted prediction and actual urban area in 2010.

Under-prediction Over-prediction Land parcel conversion





Re-adjusted prediction Actual urban area in 2010 Difference

Figure 38. Results from the test run.

Due to the extensive computational requirements of calibrating the model, as described earlier, a brute force method was used to derive parameter values. It was also one that involved the three steps of: calibration, sequentially narrowing the range of coefficient values, and increasing the data resolution. Estimation of 'fittedness' was decided by sorting the various 'runs' of the simulation test by way of the 'Lee-Sallee' metric, as described earlier, dealing with a method of measuring shape. Essentially, the metric matches the predicted growth and the natural geometry of shape, in order to determine the best simulation results among various runs.

ii. Calibrations and derive forecasting coefficients

The coarse calibration was executed with a coefficient value ranges from zero to 100 and a step of 25. Monte Carlo iteration was set to four, a low number. The results were then sorted by Lee Sallee metric, the top ten runs were shown in Table 1. Based on these top runs, the fine calibration coefficient values were adjusted: dispersion from zero to 20 with a step of five, breed zero to 20 with a step of five, spread zero to 20 with a step of five, slope zero to 100 with a step of 20, and road gravity 25-75 with a step of ten. Monte Carlo iteration was set to eight, as more accurate results were preferred than the coarse calibration. The results of the top 4 runs sorted by Lee Sallee metric were listed in Table 2. The final calibration, with further adjustment on coefficient values, was set to run with ten Monte Carlo Iterations. The coefficient values were as follow: dispersion {1 - 5, 1}, breed {12 - 17, 1}, spread {17 - 22, 1}, slope {0 - 50, 10}, and road gravity {62 - 67, 1}. These values were chosen so as to define a narrower coefficient range derived from the coarse phase of calibration.

Table 1. Top scores sorted by Lee-Sallee Metric for coarse calibration

Run	Product	Compare	Pop	Edges	Clusters	Size	Leesalee	Slope	%Urban	Xmean	Ymean	Rad
26	0.06135	0.60032	0.96772	0.92213	0.99976	0.92088	0.29004	0.9964	0.96825	0.75102	0.61373	0.96439
31	0.06135	0.60032	0.96772	0.92213	0.99976	0.92088	0.29004	0.9964	0.96825	0.75102	0.61373	0.96439
36	0.06135	0.60032	0.96772	0.92213	0.99976	0.92088	0.29004	0.9964	0.96825	0.75102	0.61373	0.96439
41	0.06135	0.60032	0.96772	0.92213	0.99976	0.92088	0.29004	0.9964	0.96825	0.75102	0.61373	0.96439
46	0.06135	0.60032	0.96772	0.92213	0.99976	0.92088	0.29004	0.9964	0.96825	0.75102	0.61373	0.96439
28	0.0445	0.6077	0.96734	0.92561	0.98493	0.94814	0.28663	0.99618	0.96788	0.56364	0.58333	0.96387
33	0.0445	0.6077	0.96734	0.92561	0.98493	0.94814	0.28663	0.99618	0.96788	0.56364	0.58333	0.96387
38	0.0445	0.6077	0.96734	0.92561	0.98493	0.94814	0.28663	0.99618	0.96788	0.56364	0.58333	0.96387
43	0.0445	0.6077	0.96734	0.92561	0.98493	0.94814	0.28663	0.99618	0.96788	0.56364	0.58333	0.96387
48	0.0445	0.6077	0.96734	0.92561	0.98493	0.94814	0.28663	0.99618	0.96788	0.56364	0.58333	0.96387

Table 2. Top runs sorted by Lee-Sallee metric for fine calibration

Run	Product	Compare	Pop	Edges	Clusters	Size	Leesalee	Slope	%Urban	Xmean	Ymean	Rad
688	0.02707	0.53936	0.97157	0.94049	0.99804	0.94005	0.2941	0.9983	0.97206	0.37674	0.56156	0.96969
694	0.02707	0.53936	0.97157	0.94049	0.99804	0.94005	0.2941	0.9983	0.97206	0.37674	0.56156	0.96969
700	0.02707	0.53936	0.97157	0.94049	0.99804	0.94005	0.2941	0.9983	0.97206	0.37674	0.56156	0.96969
706	0.02707	0.53936	0.97157	0.94049	0.99804	0.94005	0.2941	0.9983	0.97206	0.37674	0.56156	0.96969
712	0.02707	0.53936	0.97157	0.94049	0.99804	0.94005	0.2941	0.9983	0.97206	0.37674	0.56156	0.96969
718	0.02707	0.53936	0.97157	0.94049	0.99804	0.94005	0.2941	0.9983	0.97206	0.37674	0.56156	0.96969
506	0.03916	0.49991	0.96863	0.93724	0.9984	0.93329	0.2928	0.99867	0.96923	0.56916	0.59323	0.96765
512	0.03916	0.49991	0.96863	0.93724	0.9984	0.93329	0.2928	0.99867	0.96923	0.56916	0.59323	0.96765
518	0.03916	0.49991	0.96863	0.93724	0.9984	0.93329	0.2928	0.99867	0.96923	0.56916	0.59323	0.96765
524	0.03916	0.49991	0.96863	0.93724	0.9984	0.93329	0.2928	0.99867	0.96923	0.56916	0.59323	0.96765

Table 3. Top runs sorted by Lee-Sallee metric for final calibration

Run	Product	Compare	Pop	Edges	Clusters	Size	Leesalee	Slope	%Urban	Xmean	Ymean	Rad
759	0.01802	0.53624	0.97186	0.94144	0.99894	0.93688	0.29338	0.99844	0.97234	0.24817	0.57223	0.97009
765	0.01802	0.53624	0.97186	0.94144	0.99894	0.93688	0.29338	0.99844	0.97234	0.24817	0.57223	0.97009
771	0.01802	0.53624	0.97186	0.94144	0.99894	0.93688	0.29338	0.99844	0.97234	0.24817	0.57223	0.97009
777	0.01802	0.53624	0.97186	0.94144	0.99894	0.93688	0.29338	0.99844	0.97234	0.24817	0.57223	0.97009
783	0.01802	0.53624	0.97186	0.94144	0.99894	0.93688	0.29338	0.99844	0.97234	0.24817	0.57223	0.97009
789	0.01802	0.53624	0.97186	0.94144	0.99894	0.93688	0.29338	0.99844	0.97234	0.24817	0.57223	0.97009
576	0.04911	0.56649	0.97127	0.93994	0.99977	0.93117	0.29258	0.99791	0.97174	0.65361	0.56774	0.96897
582	0.04911	0.56649	0.97127	0.93994	0.99977	0.93117	0.29258	0.99791	0.97174	0.65361	0.56774	0.96897
588	0.04911	0.56649	0.97127	0.93994	0.99977	0.93117	0.29258	0.99791	0.97174	0.65361	0.56774	0.96897
594	0.04911	0.56649	0.97127	0.93994	0.99977	0.93117	0.29258	0.99791	0.97174	0.65361	0.56774	0.96897

The next step was to derive forecasting coefficients. The calibration process produces initializing coefficient values that best simulate historical growth for a region. However, due to SLEUTH's self-modification qualities, coefficient values at the start year of a run may be altered by the stop year. For forecast initialization, the stop-year values from the best calibrated coefficients are desired. Using the best coefficients derived from calibration and running of SLEUTH for the historical time period produced, a single set of stop date coefficients was identified to initialize forecasting. However, due to the random variability of the model, averaged coefficient results of many Monte Carlo Iterations produced a more robust set of forecasting coefficients (Clarke, 1997).

In this case, Monte Carlo Iterations were modified to 100. This number, in this stage, is very high in order to get more robust results. The following coefficient values were applied: dispersion {1 - 1, 1}, breed {15 - 15, 1}, spread {20 - 20, 1}, slope {1 - 1, 1}, road gravity {65 - 65, 1}. The results were sorted by both the Lee-Sallee Metric and other Optimum SLEUTH Metric. The Lee-Sallee Metric was selected for its high relevance to the growth of the shape of urban formation, which was a main focus of the research. Other Metrics, that can be used to evaluate the fit of the model, are listed here. They are: 1. Pop---Least squares regression scores for modeled urbanization, compared to the actual urbanization for the control years. 2. Edges---Least squares regression scores for a modeled urban edge count, compared to actual urban edge count for the control years. 3. Clusters---Least squares regression scores for modeled urban clustering, compared to known urban clustering for the control years. 4. Cluster Size---Least squares regression scores for modeled average urban cluster size, compared to known average urban cluster size for the control years. 5. Lee-Salle---A shape index and a measurement of the spatial fit between the model's growth and the known urban extent for the control years. 6. Slope---Least squares regression of average slope for modeled urbanized cells, compared to average slope of known urban cells for the control years. 7. % Urban--- Least squares regression of percent of available pixels urbanized, compared to the urbanized pixels for the control years. 8.

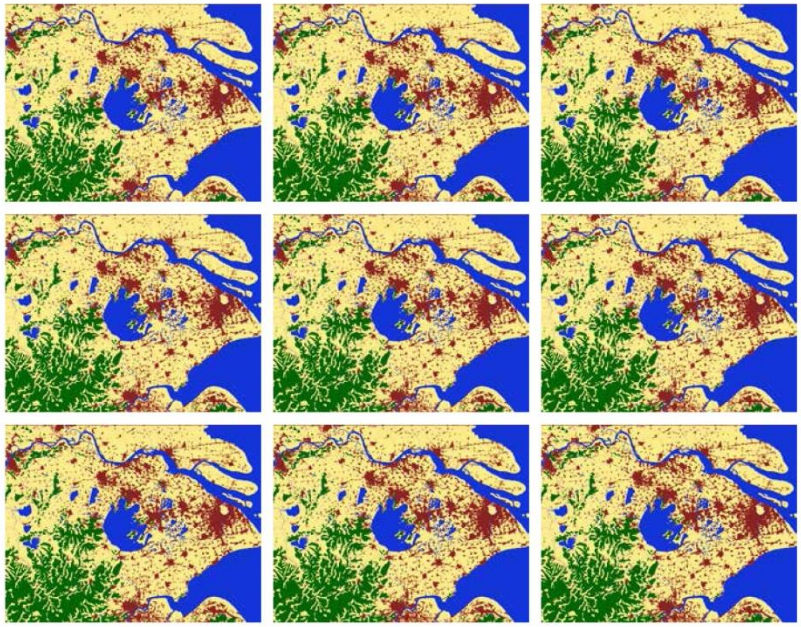
X-Mean--- Least squares regression of average x values for modeled urbanized cells, compared to average x values of known urban cells for the control years. 9. Y-Mean--- Least squares regression of average y values for modeled urbanized cells, compared to average y values of known urban cells for the control years. 10. Rad--- Least squares regression of standard radius of the urban distribution, i.e. normalized standard deviation in x and y. 11. F-Match--- A proportion of 'goodness of fit' across land use classes (Reproduced from Dietzel, 2007).

The next step after calibration was selection of coefficient ranges. The coefficient set, acquired through calibration, was used to initialize future land cover change in the region. However, SLEUTH will execute in 'predict mode' with any set of coefficients with values between zero to 100 and not necessarily derived through calibration for alternative prediction scenarios. In this model, the coefficient values used to predict growth were: dispersion - two, breed - 27, spread - 36, slope - one, and road gravity - 67. Generally, the higher the number, the stronger the influence of the coefficient in the prediction mode. For example, the road gravity has a coefficient number of 67, which is a relatively high impact factor among the growth variables.

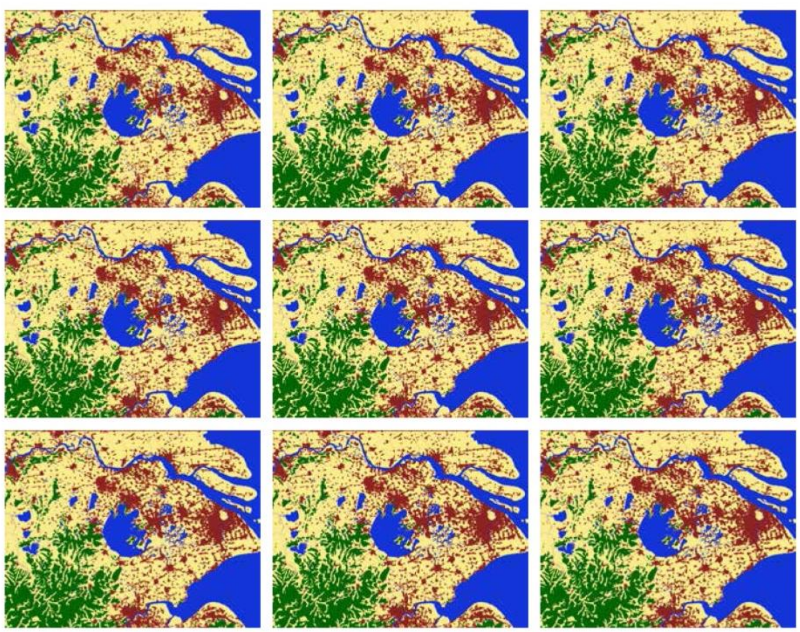
The input information was further adjusted: the starting year of urban conditions was set to be 1980 instead of 1950. This also corresponds to the initiation of modern or contemporary urban growth since the opening up to the outside world. Thus, the model used 1980, 1990, 2000, and 2010 conditions to predict the urban growth for 2011 to 2030. The predicted results were subject to further inspections. First, visual inspection for errors was applied to identify existing urbanized area. For example, the central districts of Shanghai were excluded from urban growth. A modification was made to override the existing urban condition and to reclassify these areas as urban. Second, a transit map was overlapped with a predicted map. This measure was applied to evaluate concentrated urban development around new roads to adjust road coefficients. Third, a few minor adjustments were made to test the sensitivity of coefficients that could reflect or predict certain policy changes.

iii. Model prediction

Figure 39 shows the results of forecasting runs in the study area from 2011 to 2029 at one-year intervals. Not surprisingly, substantial urbanization accrues to established towns and centers in the region. In this simulation, no attempt was made to include the Nanjing-Hangzhou expressway, nor the completed bridge and road connection to Chongming Island, to the north of central Shanghai. One interesting feature of this style of urban forecasting is the 'trace' that is registered from year to year of the growth patterns, which can then be subject to time series analysis as an 'urban flow'. Also, depending upon the parameters of a particular scenario, different end points with regard to total area of development or population are reached. In ArcGIS, the forecasting results were compared year by year and a function of 'extract' was applied to acquire the difference among the years. The graphic representations were attached in the appendix.



2011 2012 2013
2014 2015 2016
2017 2018 2019



2021 2022 2023
2024 2025 2026
2027 2028 2029

Figure 39. Forecasts for years 2011-2019, and 2021-2029.

Figure 40 shows the pattern of forecasted urban development in the study area at the terminal date of the simulation, namely in 2030. As with the other mapped depictions, also shown is the broader land mass of the Lower Changjiang Delta and the more hilly or mountainous terrain in Anhui Province to the west.

Figure 41 further highlights the pattern of forecasted urban development more accurately with respect to terrain by overlaying it onto the 'hillside' depiction of one of the basic model coefficients and background datasets. Other basic background features of the study area can also serve as the mapped underlay of the forecasted result.

Figure 42 depicts a side-by-side comparison of the results of the cellular automata simulation with that of the Lowry model described in the previous section. Despite the graphic dissimilarity, the results are reasonably similar, with the cellular automata's predictions tending to be more scattered in certain areas and less centralized. If anything, this is testament the model's capacity to mirror likely spread effects of urbanization in less than controlled circumstances.

Figure 43 shows the 2030 forecast from the cellular automata simulation in more detailed relationship to the 2010 description of urban land cover, illustrated by the dot pattern. As can be seen, the simulation is sensitive to starting positions that are already urbanized, a characteristic inherent to the conceptual structure of the model, returning back to the earlier depiction of 'neighborhoods' in the basic model.

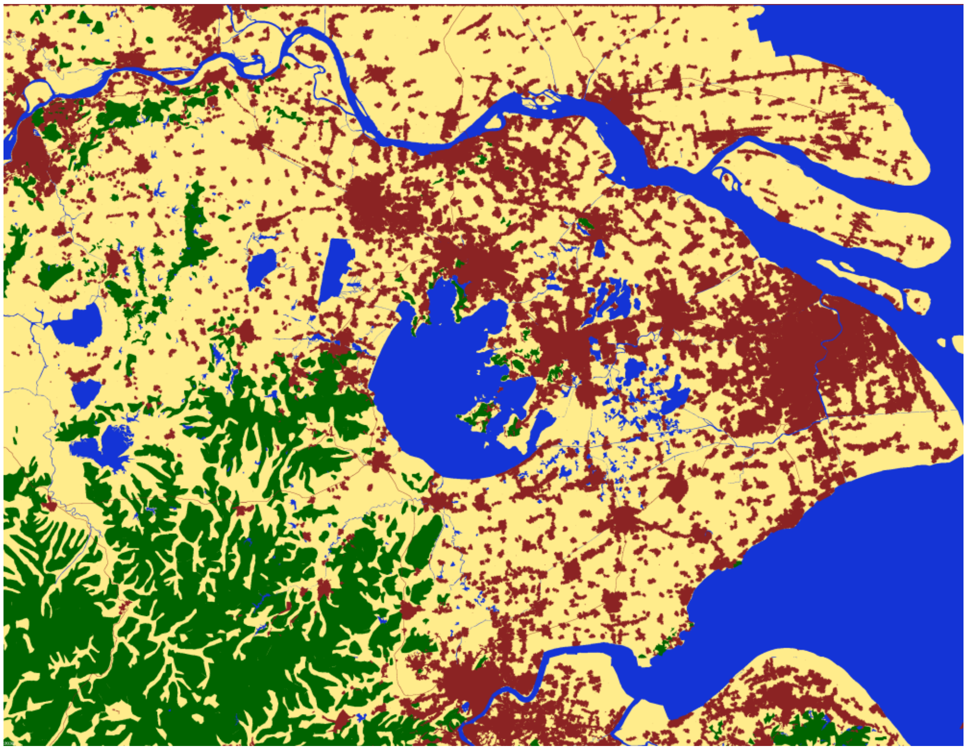


Figure 40. Forecast result for 2030.

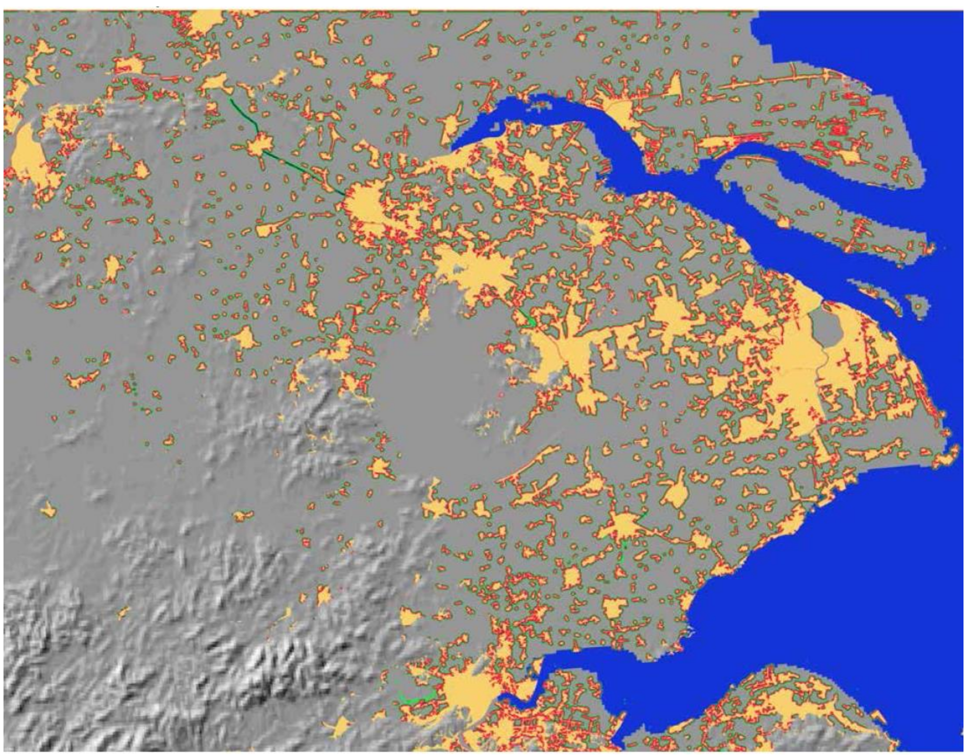


Figure 41. Result and study area terrain, 2030.

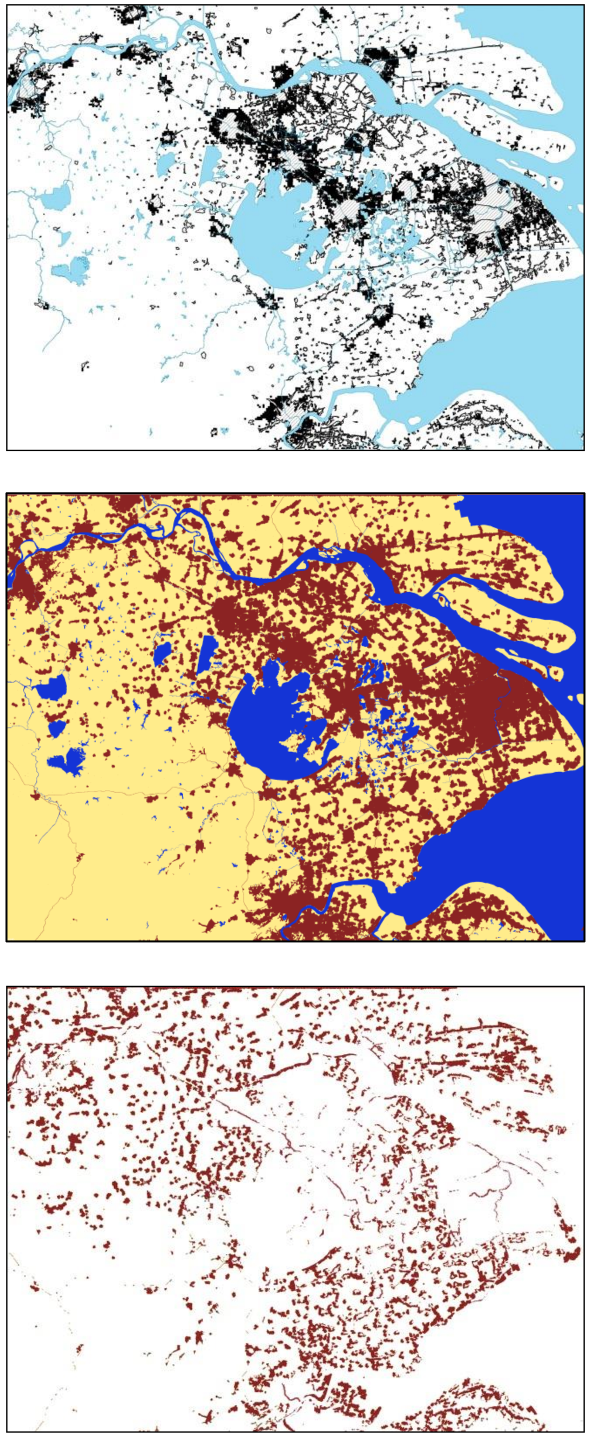


Figure 42. Comparison of projections, 2040. From top to bottom: Lowry model, Cellular Automata model, and difference between the two models.

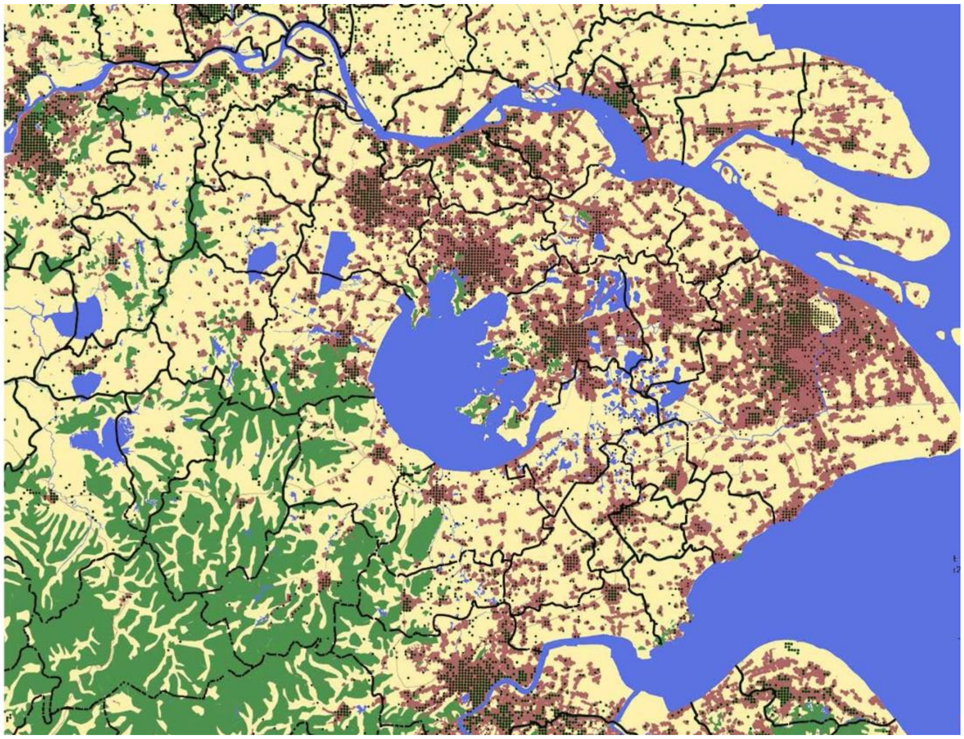
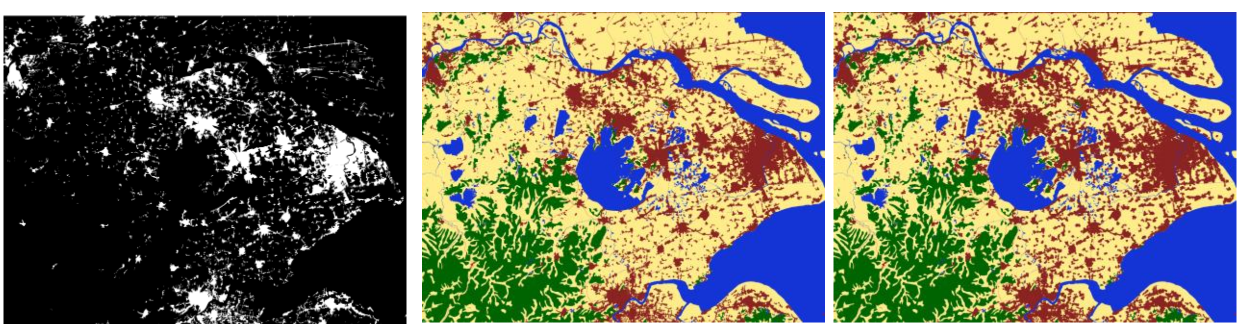


Figure 43. 2030 forecast and 2010 urban cover pattern.

By adding the Nanjing-Hangzhou expressway and the completed bridge to Chongming Island, the predicted results for 2020 and 2030 were reproduced in Figure 44, together with the actual urban condition map of 2010. The resolutions of the input images were all set at 300 dpi.



Actually map in 2010 Predicted map in 2020 Predicted map in 2030

Figure 44a. Comparison of three selected years: 2010, 2020, and 2030.
Figure 44. Cellular Automata model application in the Changjiang Delta region. In the selection process in Photoshop, under selection/ refine edge, the contrast should be set to one hundred percent, the feather be set to zero, and select similar also set to zero, otherwise selection precision will be compromised.

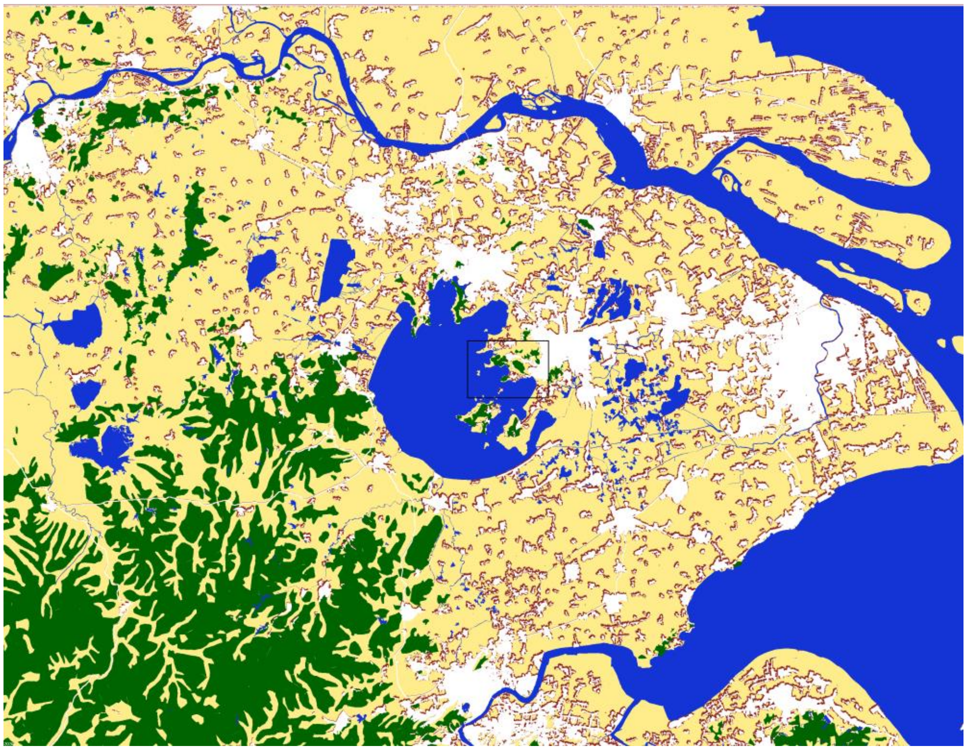


Figure 44b. Cellular Automata model predicted changes between 2010 and 2030.

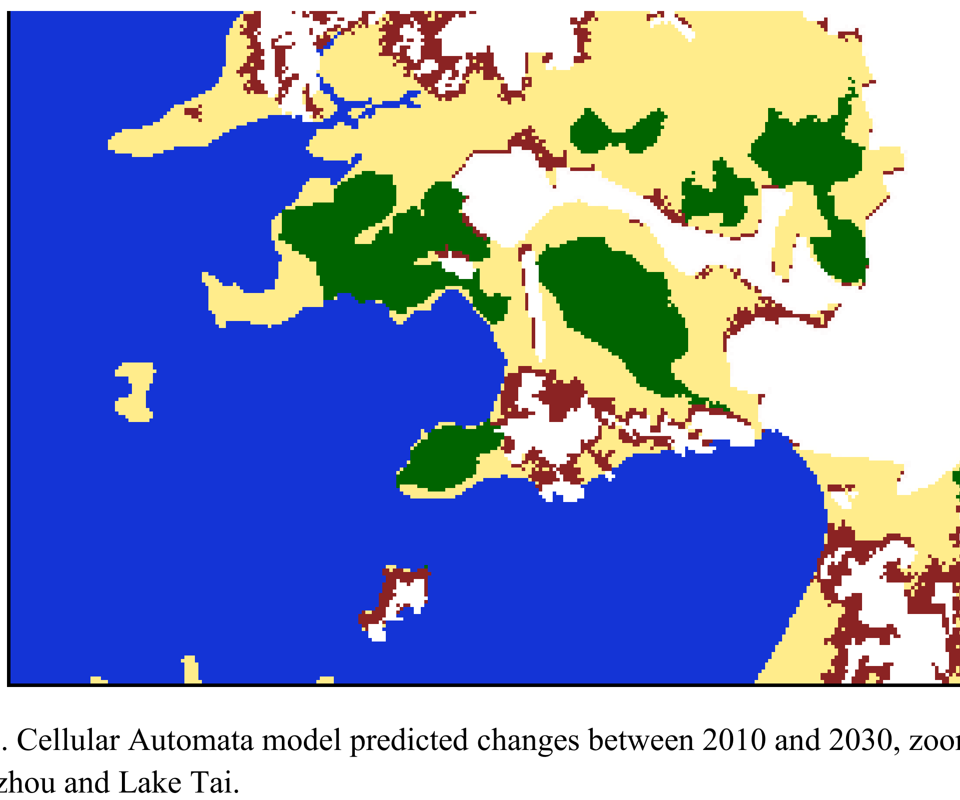


Figure 44c. Cellular Automata model predicted changes between 2010 and 2030, zoomed in around Suzhou and Lake Tai.

In summary, the locational aspects of urban growth and change potential can be examined from a variety of perspectives, ranging from relatively simple assessments to ones of increasing sophistication and dependency on iterative computational power. Relatively recent extensions of basic ‘gravity modeling’ concepts, particularly with regard to complex measures of distance coefficients appears to have enhanced both predictive and explanatory power. (Ghemawat, 2011) Also of note is the apparent convergence in terms of forecasted results among models that draw upon very different conceptual ideas ranging from those of a kind of social physics to stochastic procedures with relatively simple yet applicable rule structures and substantial amounts of computational power. The marriage between ‘urban growth models’ at the core of many of the methods presented here, with environmental databases and Geographic Information Systems has also appreciably improved representational capacities, as well as the interaction of dynamic and centripetal interactions with those that are more centrifugal than place-centered. Although of practical use these approaches may be, their more purely explanatory power is still lacking, relying as they often do upon relatively crude physical analogies, or natural evolutionary processes in the case of cellular automata (Rowe, 2013).

Table 4. Selected Monte Carlo Iteration for model prediction

MC	*Year*	*Diffusion*	*Breed*	*Spread*	*SlopeResist*	*RoadGrav*
1	*2011*	*2.02*	*27.27*	*36.36*	*1.00*	*67.16*
1	*2012*	*2.04*	*27.54*	*36.72*	*1.00*	*67.32*
1	*2013*	*2.06*	*27.82*	*37.09*	*1.00*	*67.49*
1	*2014*	*2.08*	*28.10*	*37.46*	*1.00*	*67.68*
1	*2015*	*2.10*	*28.38*	*37.84*	*1.00*	*67.87*
1	*2016*	*2.12*	*28.66*	*38.21*	*1.00*	*68.08*
1	*2017*	*2.14*	*28.95*	*38.60*	*1.00*	*68.29*
1	*2018*	*2.17*	*29.24*	*38.98*	*1.00*	*68.52*
1	*2019*	*2.19*	*29.53*	*39.37*	*1.00*	*68.76*
1	*2020*	*2.21*	*29.82*	*39.77*	*1.00*	*69.01*
1	*2021*	*2.23*	*30.12*	*40.16*	*1.00*	*69.26*
1	*2022*	*2.25*	*30.42*	*40.57*	*1.00*	*69.54*
1	*2023*	*2.28*	*30.73*	*40.97*	*1.00*	*69.82*
1	*2024*	*2.30*	*31.04*	*41.38*	*1.00*	*70.11*

1	2025	2.32	31.35	41.79	1.00	70.42
1	2026	2.35	31.66	42.21	1.00	70.74
1	2027	2.37	31.98	42.63	1.00	71.06
1	2028	2.39	32.30	43.06	1.00	71.40
1	2029	2.42	32.62	43.49	1.00	71.76
1	2030	2.44	32.95	43.93	1.00	72.12

The results of the Cellular Automata model prediction showed an urbanization rate, based on land area, which increased from 15.106% in 2011 to 21.0457% in 2030. The following observations were made about the results and some methods to improve the model were proposed.

1. Prediction based on the proposed new transit system: the model used data from 1980 to 2010, but not the planned future transit connections. Results can be improved with newly proposed rail systems to predict 2030 urban growth.

2. Create animation for visualization: compile the 'whirlgif' files between running the model. It helps to improve visual inspections for errors.

3. Spatial Representation. To better represent simulation results visually.

4. Extend the prediction to more than 20 years. Increase SIZE_CIR_Q and recompile. However, the downside of pursuing such a forecast is unpredictable 'turning points'. A turning point is any significant event that alters the direction of urbanization process. For example, in the early 1960s in China, the 'go up to the mountain and go out to the village' movement changed the urban growth curve and reduced the urban population for a few years.

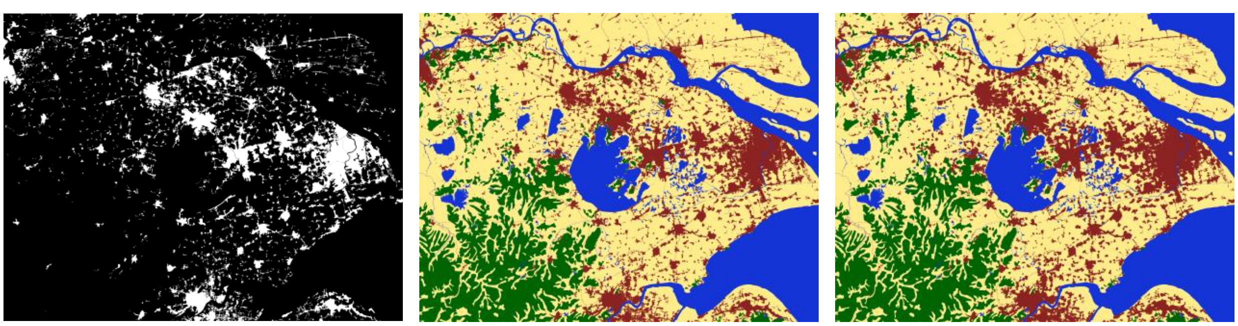
5. Land use mapping and the creation of more comprehensive maps to reflect not only the urban network but ecological network as well.

6. Fuzzy set theory to show in reality, urbanization is not a true or false condition, and very often there is no hard edge between non-urban or urban. It should also include the states of 'in between', like twenty percent urban or eighty percent urban, for example.

b. Scenario Cellular Automata model prediction of urban growth

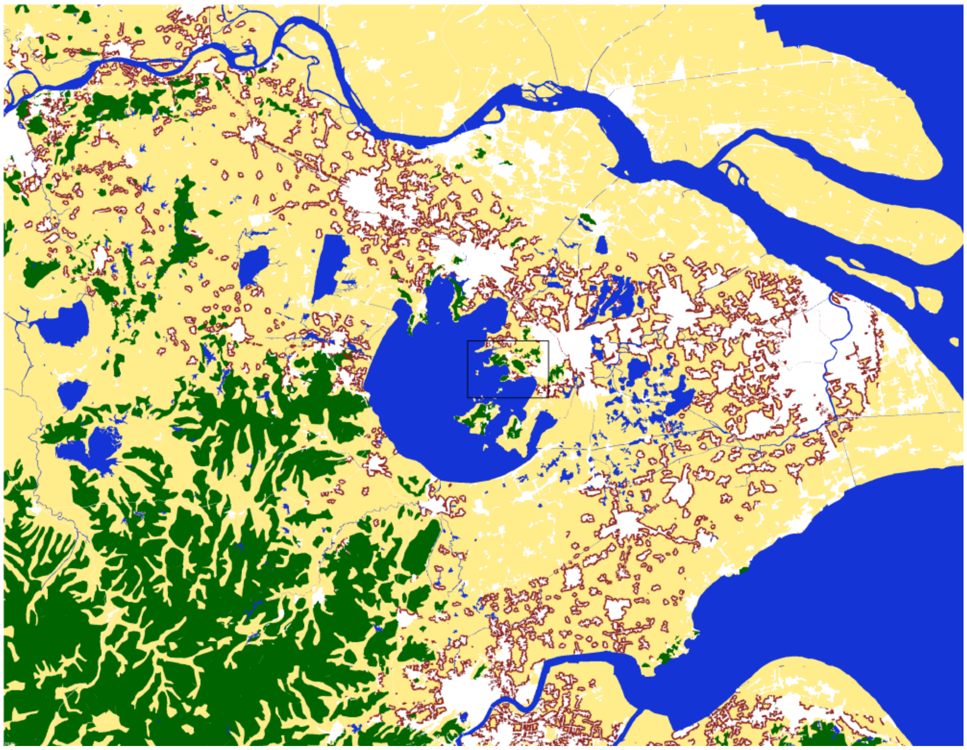
With considerations from the above model prediction, a Scenario Cellular Automata model was calibrated with improved running coefficients and input data. For each of the four selected scenarios, the Scenario Cellular Automata model was modified to reflect the specific conditions. The Scenario Cellular Automata produced annual urban growth predictions from 2011 to 2030 for 20 consecutive years. It did so by calibrating the historical data on an annual basis and recalibrating the yearly predicted growth for the following year's prediction. The results of the four scenarios are listed as follows:

First, the results of scenario 1: development corridors showed an urbanization rate, based on land area, which increased from 15.077% in 2011 to 20.366% in 2030. Figure 45a is the comparison of three selected years: 2010, 2020, and 2030. In the 2010 actual map, the white area represents urbanized land parcels and black represents others. In both the 2020 predicted map and the 2030 predicted map, the red area represents urbanized land parcels, the blue represents water surfaces, the green represents forests, and the sandy brown represents other un-urbanized land parcels. Figure 45b is the predicted changes between 2010 and 2030. In it, the red area represents the predicted changes between 2010 and 2030, the white represents already urbanized land parcels in 2010, the blue represents water surfaces, the green represents forests, and the sandy brown represents other un-urbanized land parcels. Figure 45c is the enlarged image of predicted changes in around Suzhou and Lake Tai.

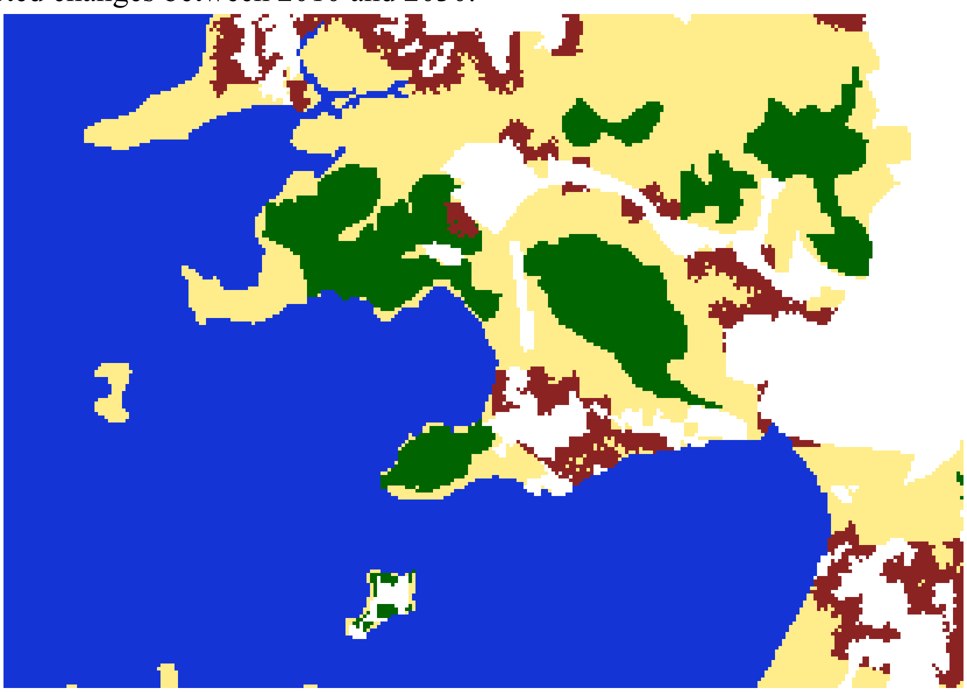


2010 actual map 2020 predicted map 2030 predicted map

45a. Comparison of three selected years: 2010, 2020, and 2030.



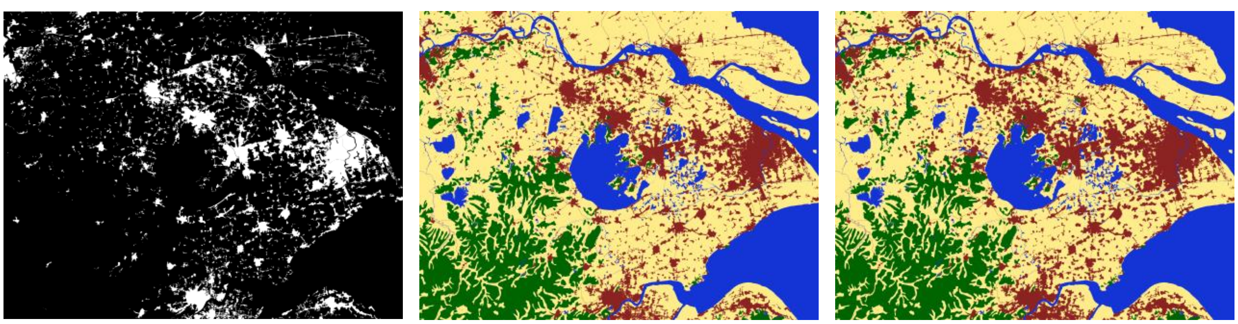
45b. Predicted changes between 2010 and 2030.



45c. Predicted changes in around Suzhou and Lake Tai, between 2010 and 2030.

Figure 45. Scenario Cellular Automata model projections of urban growth from 2011 to 2030 for scenario 1: development corridors.

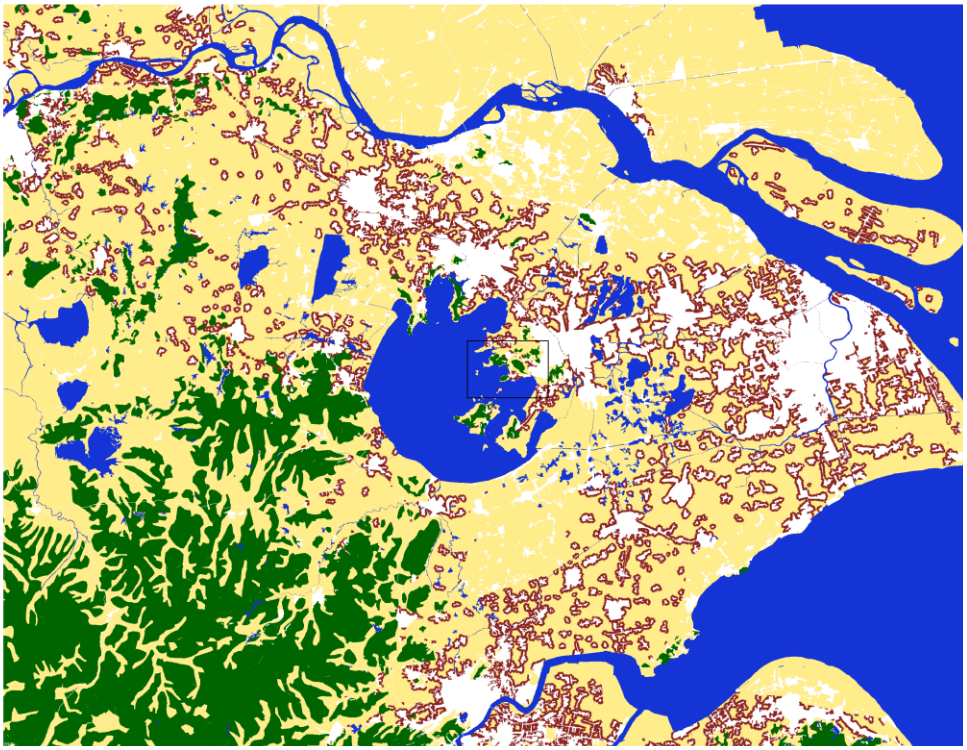
The results of scenario 2: development corridors, big city growth predicted an urbanization rate, based on land area, which increased from 15.341% in 2011 to 26.129% in 2030. Figure 46a is the comparison of three selected years: 2010, 2020, and 2030. In the 2010 actual map, the white area represents urbanized land parcels and black represents others. In both the 2020 predicted map and the 2030 predicted map, the red area represents urbanized land parcels, the blue represents water surfaces, the green represents forests, and the sandy brown represents other un-urbanized land parcels, as before. Figure 46b is the predicted changes between 2010 and 2030. In it, the red area represents the predicted changes between 2010 and 2030, the white represents already urbanized land parcels in 2010, the blue represents water surfaces, the green represents forests, and the sandy brown represents other un-urbanized land parcels, also as before. Figure 46c is the enlarged image of predicted changes in around Suzhou and Lake Tai.



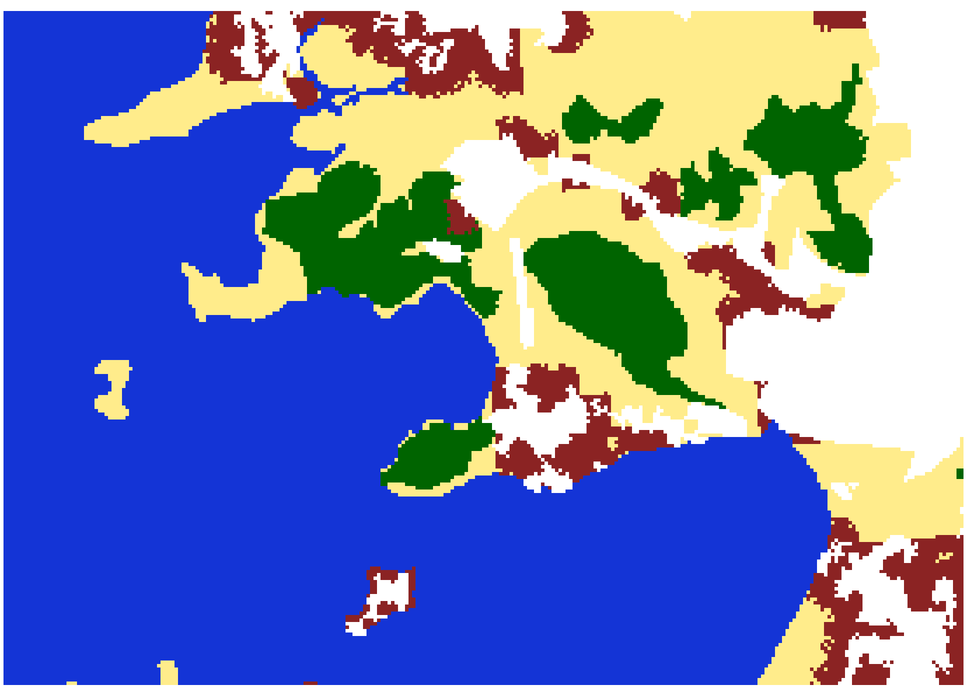
2010 actual map 2020 predicted map 2030 predicted map

46a. Comparison of three selected years: 2010, 2020, and 2030.

Figure 46. Scenario Cellular Automata model projections of urban growth from 2011 to 2030 for scenario 2: development corridors, plus big city growth.

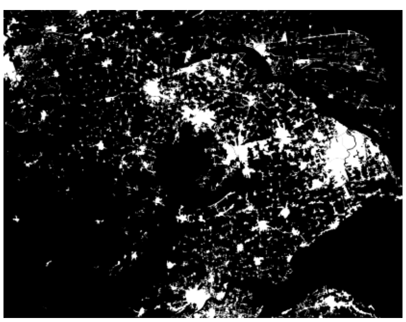


46b. Predicted changes between 2010 and 2030.

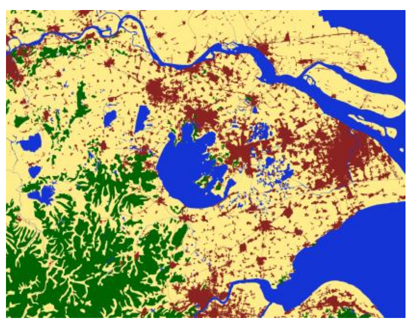


46c. Predicted changes in around Suzhou and Lake Tai, between 2010 and 2030.

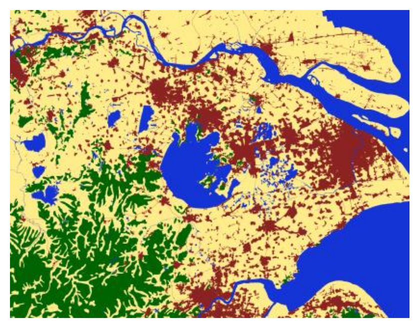
The results of scenario 3: ecological concerns, plus development corridors predicted an urbanization rate, based on land area, which increased from 15.077% in 2011 to 20.285% in 2030. Figure 47a is the comparison of three selected years: 2010, 2020, and 2030. In the 2010 actual map, the white area represents urbanized land parcels and black represents others, as earlier. In both the 2020 predicted map and the 2030 predicted map, the red area represents urbanized land parcels, the blue represents water surfaces, the green represents forests, and the sandy brown represents other un-urbanized land parcels, again as earlier. Figure 47b is the predicted changes between 2010 and 2030. In it, the red area represents the predicted changes between 2010 and 2030, the white represents already urbanized land parcels in 2010, the blue represents water surfaces, the green represents forests, and the sandy brown represents other un-urbanized land parcels, as before. Figure 47c is the enlarged image of predicted changes in around Suzhou and Lake Tai.



2010 actual map



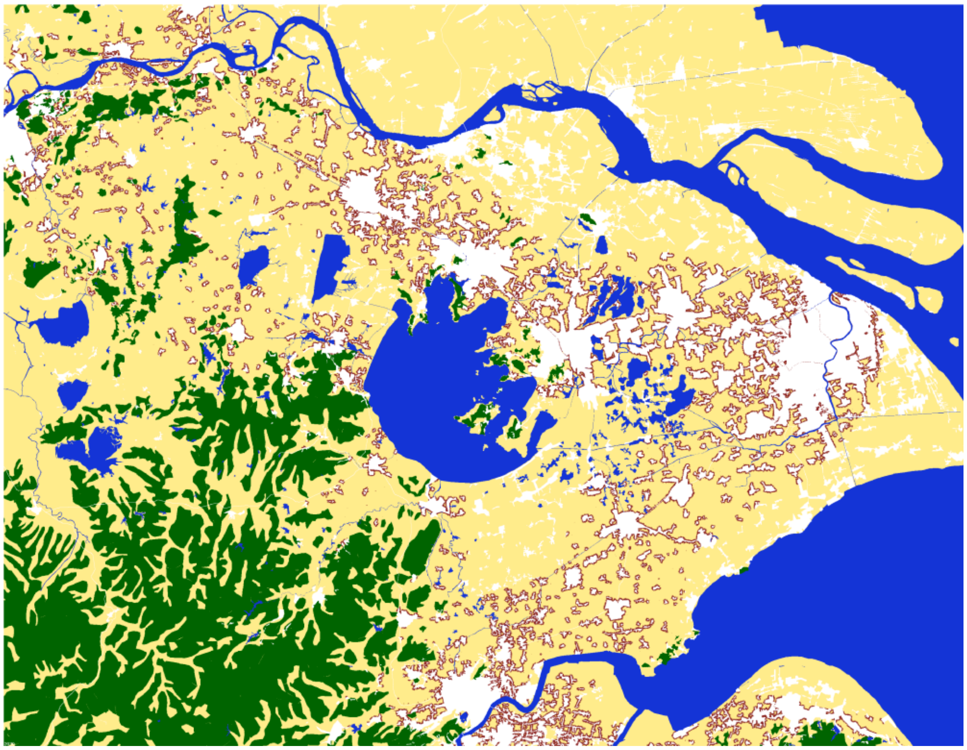
2020 predicted map



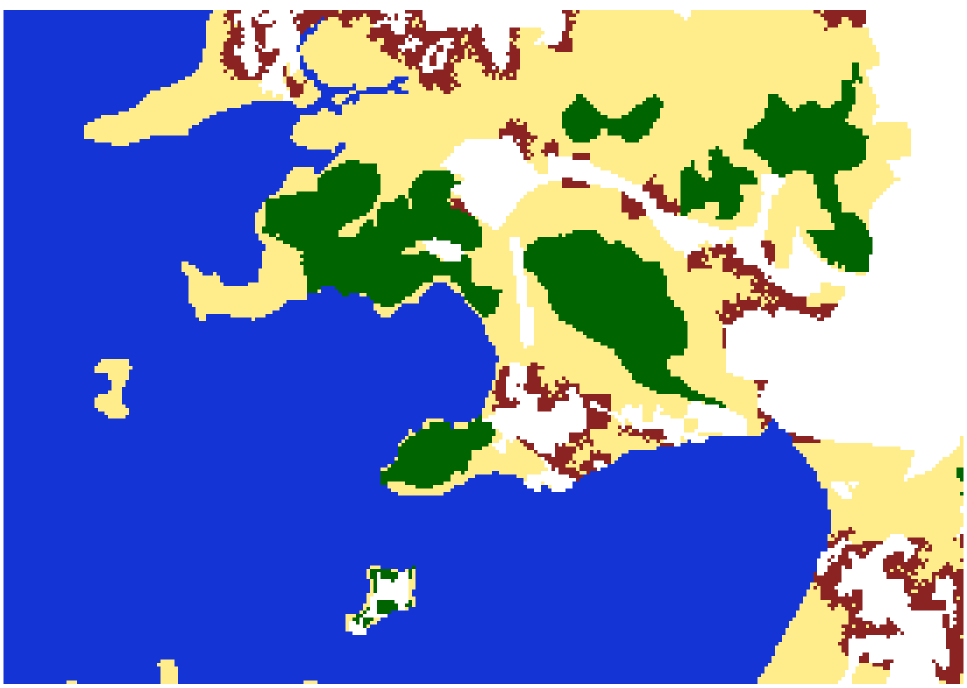
2030 predicted map

47a. Comparison of three selected years: 2010, 2020, and 2030.

Figure 47. Scenario Cellular Automata model projections of urban growth from 2011 to 2030 for scenario 3: ecological system concern, plus development corridors.

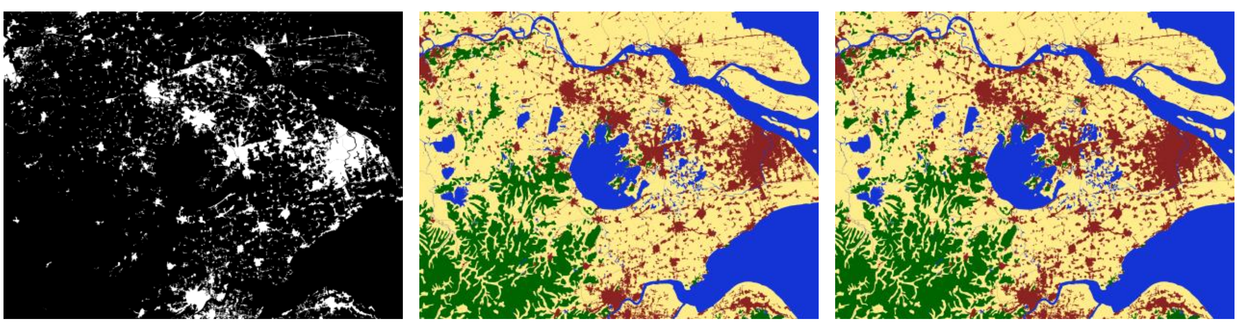


47b. Predicted changes between 2010 and 2030.



47c. Predicted changes in around Suzhou and Lake Tai, between 2010 and 2030.

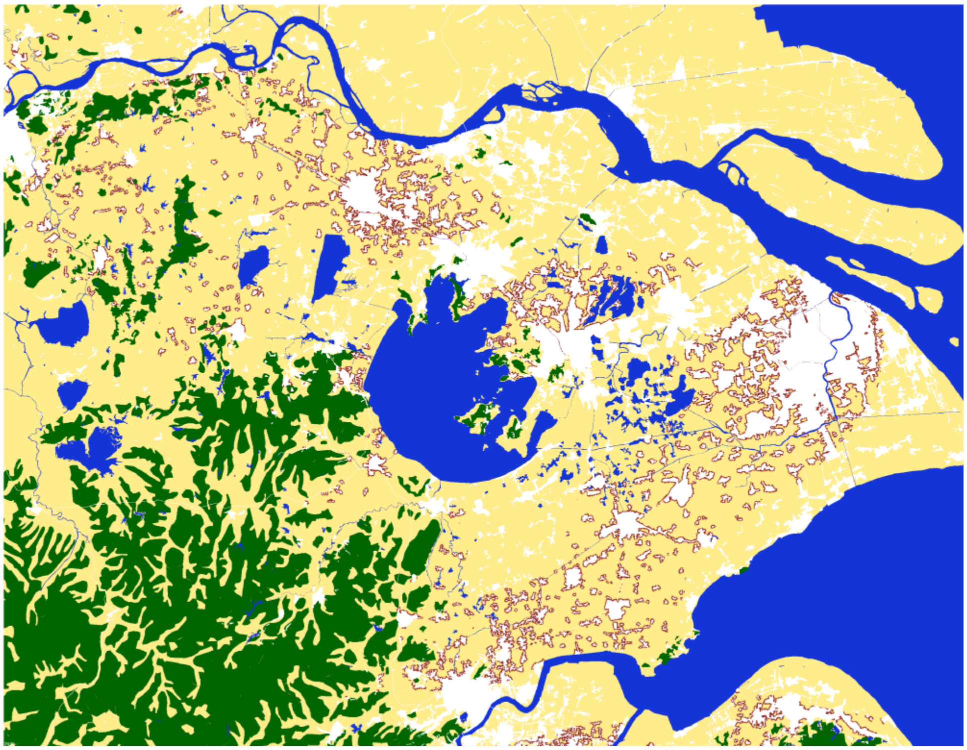
The results of the scenario 4: disaster prevention, plus development corridors predicted an urbanization rate, based on land area, which increased from 15.021% in 2011 to 18.520% in 2030. Figure 48a is the comparison of three selected years: 2010, 2020, and 2030. In the 2010 actual map, the white area represents urbanized land parcels and black represents others, as earlier. In both the 2020 predicted map and the 2030 predicted map, the red area represents urbanized land parcels, the blue represents water surfaces, the green represents forests, and the sandy brown represents other un-urbanized land parcels, again as earlier. Figure 48b is the predicted changes between 2010 and 2030. In it, the red area represents the predicted changes between 2010 and 2030, the white represents already urbanized land parcels in 2010, the blue represents water surfaces, the green represents forests, and the sandy brown represents other un-urbanized land parcels, as before. Figure 48c is the enlarged image of predicted changes in around Suzhou and Lake Tai.



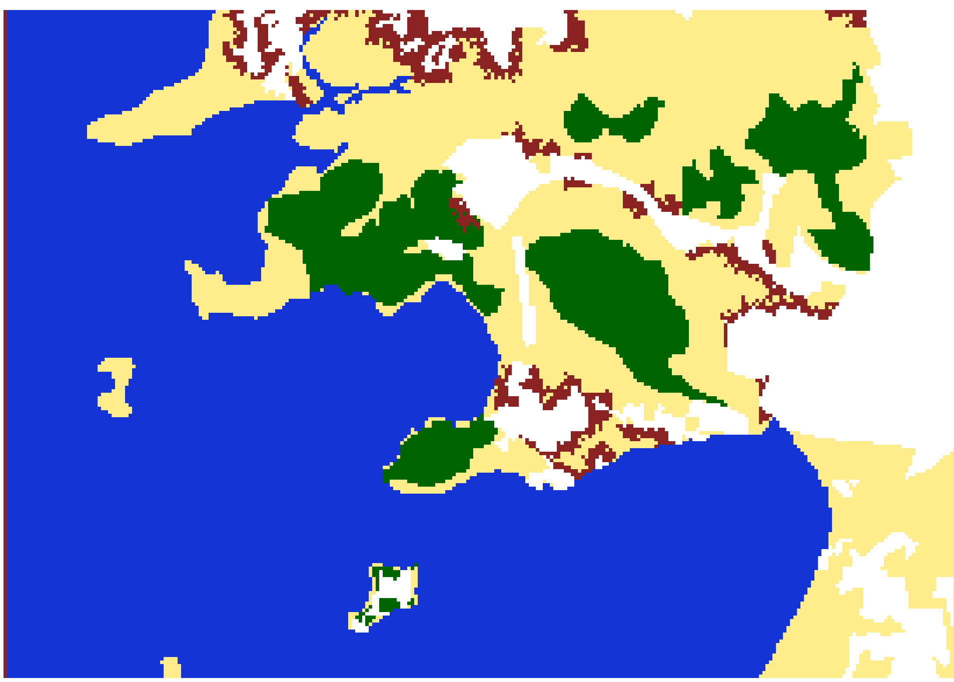
2010 actual map 2020 predicted map 2030 predicted map

48a. Comparison of three selected years: 2010, 2020, and 2030.

Figure 48. Scenario Cellular Automata model projections of urban growth from 2011 to 2030 for scenario 4: disaster prevention, plus development corridors.



48b. Predicted changes between 2010 and 2030.



48c. Predicted changes in around Suzhou and Lake Tai, between 2010 and 2030.

c. Results from the three baselines

i. Baseline 1. Environmental suitability

The result of the environmental suitability study is shown in Figure 49. It included an overlay of urban development in the region as of 2010. Basically the most suitable areas are colored in green and the least suitable areas are colored in red. As observed, a number of cities like Shanghai, for instance, are located in mostly unsuitable circumstances. The image was modeled based on Saehoon Kim's doctoral dissertation at GSD, 2012 with adjustment on regional boundary and variable selections (Kim, 2012). In Kim's dissertation, the suitability study was measured based on per capita, whereas in this research, the unit was per land parcel.

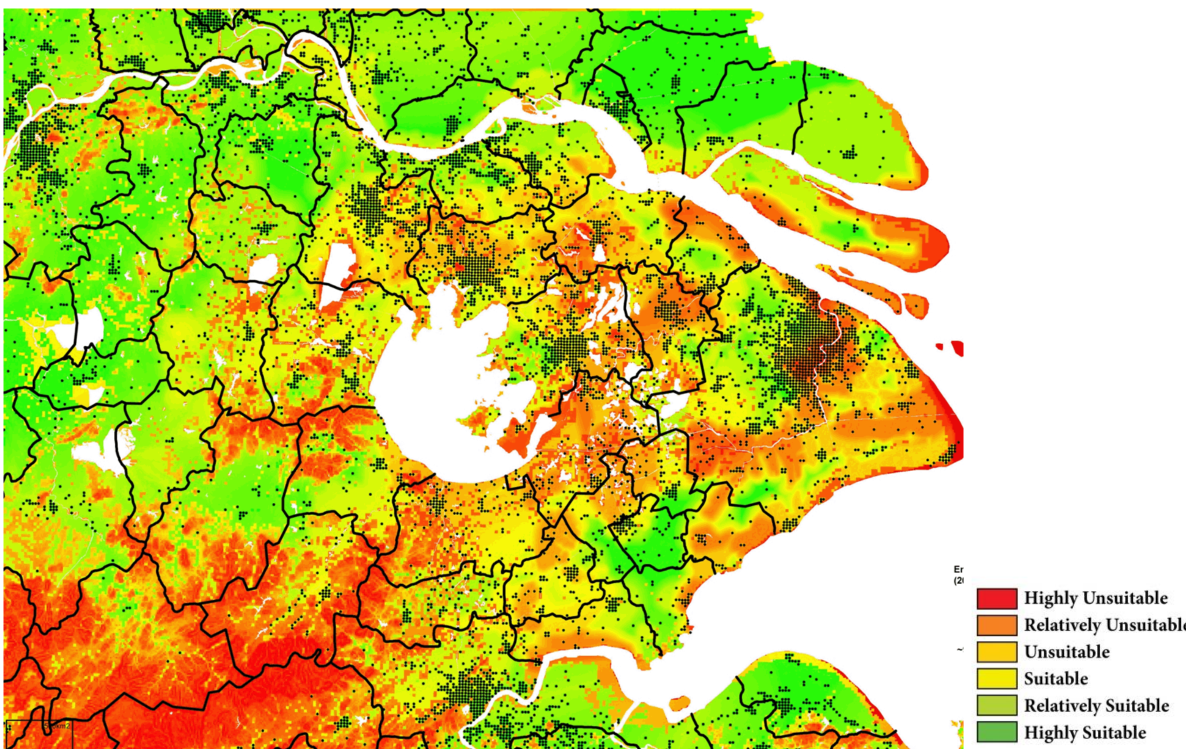


Figure 49. Environmental suitability of the Changjiang Delta Region, 2010.

What mattered most, in this research, was to identify the areas that were most unsuitable, or even hazardous, for urban development. In Figure 50, the red areas were extracted as the baseline image for environmental suitability. The more encroachment of urban development in those areas, represented by red color grid cells, the less sensible of a growth scenario concerned environmental issues. A quick visual inspection revealed that the coastal lines, areas around Lai Tai, and the southwestern mountainous region were clustered as environmentally sensitive areas deemed not suitable for urban development.

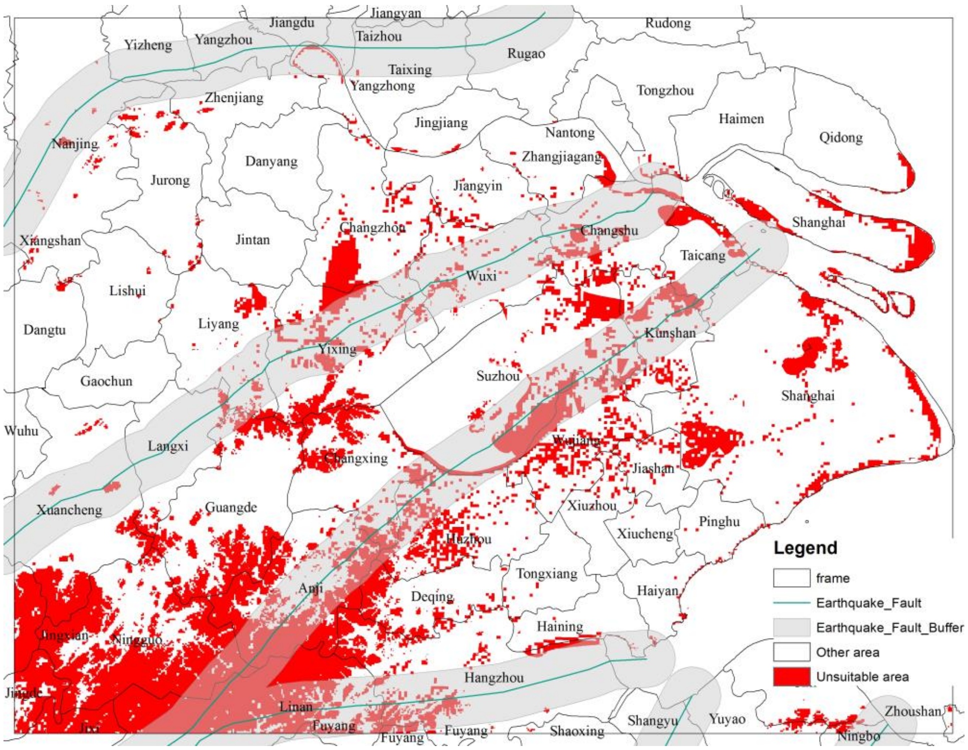


Figure 50. Environmentally unsuitable area for urban development in the Changjiang Delta Region, 2010.

ii. Baseline 2. Economic performance

The variables concerning economic performances were projected in the ArcGIS map of the Changjiang Delta Region. These three maps represented investment, revenue, and production. Together with the Economic Performance Index, they revealed basic economic conditions of the Changjiang Delta Region in 2010.

The investment variable, known as the 'national fixed asset investment in urban service facilities', included financial allocation from the central government budget, financial allocation from the local government budget, domestic loan, securities, foreign investment and foreign direct investment, and self-raised funds and self-owned funds. The results were classified with natural breaks into ten categories. This sought to partition data into classes based on natural groups in the data distribution, rather than arbitrary ones. Natural breaks occur in the histogram at the low points, or valleys. Breaks were assigned in the order of the size of the valleys, with the largest valley being assigned the first natural break. The break values were not rounded to maintain the natural distribution of cities and counties in each category. A quick visual inspection revealed that Shanghai and Nanjing, as well as some high value cities north of Lake Tai, such as Wuxi were the most prominent (reddish area in Figure 51). The visual inspection didn't quantify the distribution pattern but provided a good point of departure for understanding the economic conditions of the region.

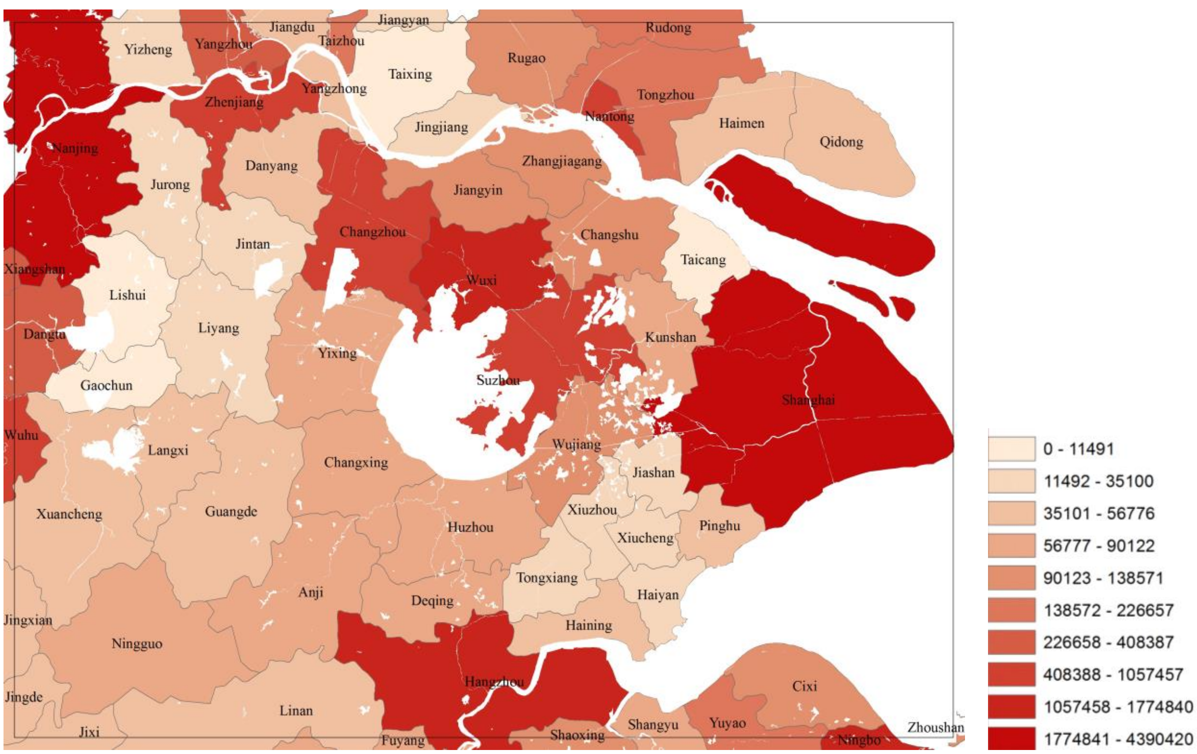


Figure 51. The national fixed asset investment in urban service facilities by cities and counties, 2010. Source: China Urban Construction Statistical Yearbook 2011.

The revenue variable, known as the revenue of urban maintenance, included urban maintenance and construction tax, extra-charges for municipal utilities, fee for expansion of municipal utilities capacity, fee for use of municipal utilities, tolls on roads and bridges, water treatment fee, garbage treatment fee, land transfer revenue, water resource fee, and revenues. The results were classified again with natural breaks of ten categories. A quick visual inspection revealed that Shanghai, Nanjing, and Hangzhou composed the tripod of the region. Some other high value cities were located north of Lake Tai, such as Suzhou (reddish area in Figure 52).

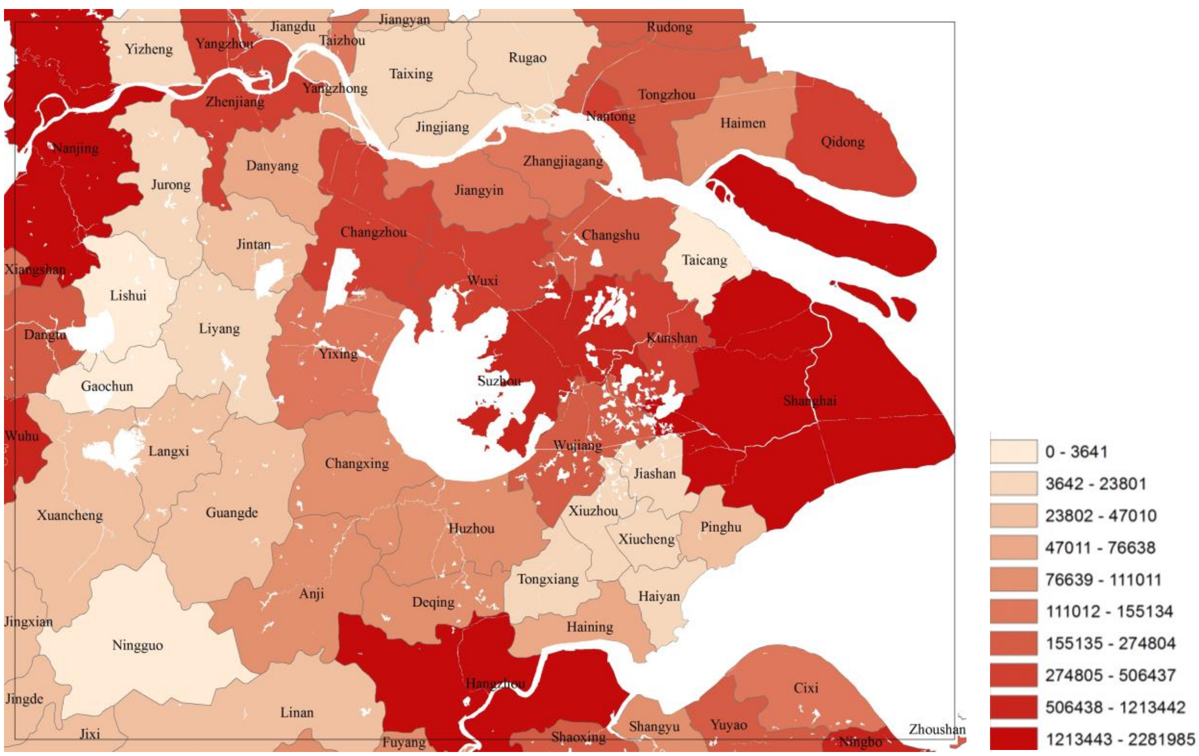


Figure 52. The revenue of urban maintenance by cities and counties, 2010.
Source: China Urban Construction Statistical Yearbook 2011.

GDP, one of the most commonly used variables for economic studies, was applied. The results were classified with natural breaks of ten categories. A quick visual inspection revealed that Shanghai was the ‘dragon head’ leading the economic growth of the Changjiang Delta Region (Figure 53).

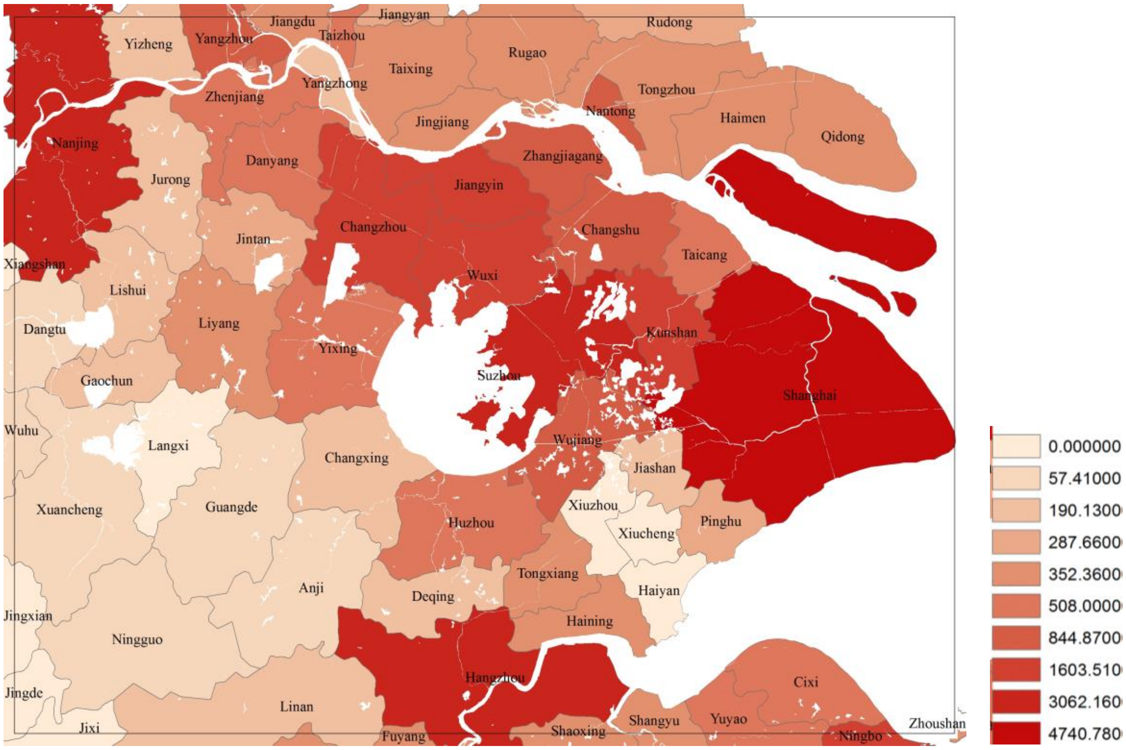


Figure 53. Gross Domestic Production (GDP) spatial distribution by cities and counties, 2010. Source: China Urban Construction Statistical Yearbook 2011.

The use of investment, revenue, and GDP were often associated with per capita value. However, this research applied the actual numbers without normalization by population. The reason was because all three variables were based on the administrative boundary, not normalized by the population that resides within. It reinforced the idea that the research was based on the land parcels subdivided into grid cells and the data collection followed the same kind of measurement, which were land based.

The three variables were put into the equation for Economic Performance Index, using Weighted Linear Combination method. The result of the economic performance study was shown in Figure 54. It included an overlay of administrative district boundaries as of 2010. In Table 5, the national fix assets investment in urban service facilities by industry, revenue of urban maintenance, and Gross Domestic Product were listed by city. Table 6 revealed the results from the normalization process and the Economic Performance Scores of each city and their relative rankings within the Changjiang Delta Region urban network.

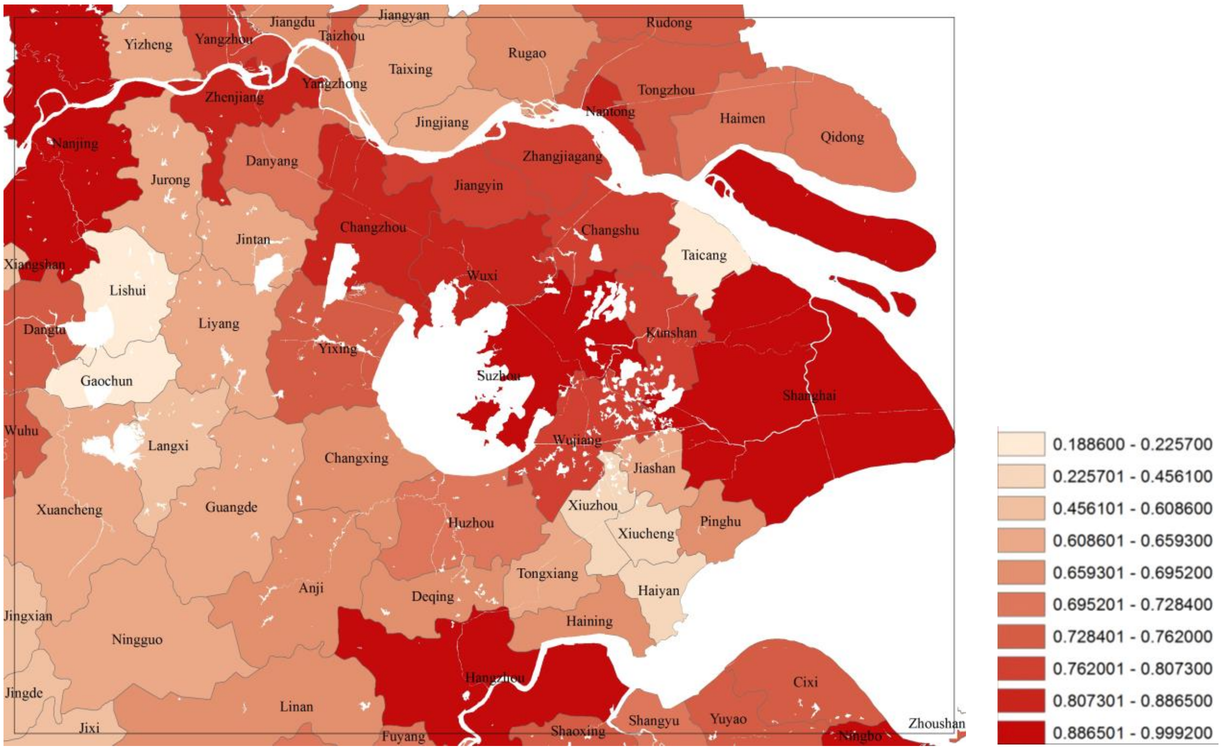


Figure 54. Economic Performance Index spatial distribution by cities and counties, 2010.

FID	City	Province	National Fix Assets Investment in Urban Service Facilities by Industry	Revenue of Urban Maintenance	Gross Domestic Product (GDP)	GDP/ Capita	Population
0	Zhoushan	Zhejiang	126,021	188,402	457	-	-
1	Wuxi	Jiangsu	1,774,840	506,437	2,987	-	-
2	Changzhou	Jiangsu	701,173	310,752	2,316	-	-
3	Shanghai	Shanghai	4,390,420	2,200,745	16,972	-	-
4	Ningbo	Zhejiang	1,702,886	916,788	3,062	-	-
5	Suzhou	Jiangsu	1,057,457	1,213,442	3,573	-	-
6	Zhenjiang	Jiangsu	847,204	410,418	845	-	-
7	Nanjing	Jiangsu	3,062,884	2,043,181	4,515	-	-
8	Nantong	Jiangsu	1,016,117	458,421	1,393	-	-
9	Hangzhou	Zhejiang	1,315,025	2,281,985	4,741	-	-
10	Shaoxing	Zhejiang	101,847	196,232	467	-	-
11	Lishui	Jiangsu	0	0	250	-	-
12	Gaochun	Jiangsu	0	0	247	-	-
13	Jiangyin	Jiangsu	115,380	125,963	2,001	-	-
14	Yixing	Jiangsu	83,424	143,471	806	-	-
15	Liyang	Jiangsu	31,840	20,097	425	-	-
16	Jintan	Jiangsu	28,735	36,936	308	-	-
17	Changshu	Jiangsu	95,888	193,012	1,454	-	-
18	Zhangjiagang	Jiangsu	138,571	155,134	1,604	-	-
19	Kunshan	Jiangsu	90,122	328,668	2,100	-	-
20	Wujiang	Jiangsu	99,293	226,897	1,003	-	-
21	Taicang	Jiangsu	0	0	730	-	-
22	Rudong	Jiangsu	181,611	258,421	352	-	-
23	Qidong	Jiangsu	38,992	347,862	430	-	-
24	Rugao	Jiangsu	102,376	22,309	431	-	-
25	Tongzhou	Jiangsu	181,611	208,421	508	-	-
26	Haimen	Jiangsu	41,191	104,029	500	-	-
27	Yangzhou	Jiangsu	408,387	335,839	989	-	-
28	Yizheng	Jiangsu	29,465	15,052	278	-	-
29	Jiangdu	Jiangsu	40,838	33,583	486	-	-
30	Danyang	Jiangsu	47,841	76,638	608	-	-
31	Yangzhong	Jiangsu	56,776	60,646	247	-	-
32	Jurong	Jiangsu	27,930	23,801	243	-	-
33	Taizhou	Jiangsu	226,657	141,556	567	-	-
34	Jingjiang	Jiangsu	21,684	11,937	441	-	-
35	Taixing	Jiangsu	11,491	11,999	408	-	-
36	Jiangyan	Jiangsu	26,913	29,843	307	-	-
37	Fuyang	Zhejiang	76,254	102,446	416	-	-
38	Linan	Zhejiang	52,656	47,010	288	-	-
39	Yuyao	Zhejiang	189,133	221,041	568	-	-
40	Cixi	Zhejiang	101,542	143,089	757	-	-
41	Xiucheng	Zhejiang	34,100	21,290	0	-	-
42	Xiuzhou	Zhejiang	35,100	22,300	0	-	-
43	Jiashan	Zhejiang	34,200	21,350	276	-	-
44	Haiyan	Zhejiang	33,800	20,970	0	-	-
45	Haining	Zhejiang	47,645	60,717	456	-	-
46	Pinghu	Zhejiang	41,714	31,086	341	-	-
47	Tongxiang	Zhejiang	25,153	14,008	409	-	-
48	Huzhou	Zhejiang	70,023	90,400	596	-	-
49	Deqing	Zhejiang	69,020	89,400	240	-	-
50	Changxing	Zhejiang	68,100	88,500	284	-	-
51	Anji	Zhejiang	69,100	89,500	190	-	-
52	Shangyu	Zhejiang	83,551	111,011	436	-	-
53	Wuhu	Anhui	768,012	739,995	103	-	-
54	Xiangshan	Anhui	296,900	137,402	0	-	-
55	Dangtu	Anhui	295,600	274,804	189	-	-
56	Xuancheng	Anhui	53,020	35,080	148	-	-
57	Langxi	Anhui	42,130	34,590	57	-	-
58	Guangde	Anhui	40,350	33,020	99	-	-
59	Jingxian	Anhui	41,560	35,690	47	-	-
60	Jixi	Anhui	42,780	37,020	33	-	-
61	Jingde	Anhui	39,820	32,500	20	-	-
62	Ningguo	Anhui	66,822	36,410	130	-	-

Table 5. Economic performance variables and data collections, 2010

FID	City	Province	Natural Logarithm of National Fix Assets Investment in Urban Service	Natural Logarithm of Revenue of Urban Maintenance	Natural Logarithm of Gross Domestic Product (GDP)	Normalizing Investment by Scaling Between 0 and 1	Normalizing Revenue by Scaling Between 0 and 1	Normalizing GDP by Scaling Between 0 and 1	Economic Performance Scores	Rank
0	Zhoushan	Zhejiang	11.7442	12.1463	6.1236	0.7678	0.8296	0.6288	0.7421	23
1	Wuxi	Jiangsu	14.3892	13.1352	8.0019	0.9408	0.8972	0.8216	0.8865	6
2	Changzhou	Jiangsu	13.4605	12.6468	7.7477	0.8801	0.8638	0.7955	0.8465	7
3	Shanghai	Shanghai	15.2949	14.6043	9.7393	1.0000	0.9975	1.0000	0.9992	1
4	Ningbo	Zhejiang	14.3478	13.7286	8.0269	0.9381	0.9377	0.8242	0.9000	5
5	Suzhou	Jiangsu	13.8714	14.0090	8.1811	0.9069	0.9569	0.8400	0.9013	4
6	Zhenjiang	Jiangsu	13.6497	12.9249	6.7392	0.8924	0.8828	0.6920	0.8224	9
7	Nanjing	Jiangsu	14.9349	14.5300	8.4152	0.9765	0.9924	0.8640	0.9443	2
8	Nantong	Jiangsu	13.8315	13.0355	7.2391	0.9043	0.8904	0.7433	0.8460	8
9	Hangzhou	Zhejiang	14.0894	14.6406	8.4640	0.9212	1.0000	0.8691	0.9301	3
10	Shaoxing	Zhejiang	11.5312	12.1871	6.1457	0.7539	0.8324	0.6310	0.7391	25
11	Lishui	Jiangsu	0.0000	0.0000	5.5221	0.0000	0.0000	0.5670	0.1890	62
12	Gaochun	Jiangsu	0.0000	0.0000	5.5104	0.0000	0.0000	0.5658	0.1886	63
13	Jiangyin	Jiangsu	11.6560	11.7437	7.6014	0.7621	0.8021	0.7805	0.7816	13
14	Yixing	Jiangsu	11.3317	11.8739	6.6919	0.7409	0.8110	0.6871	0.7463	22
15	Liyang	Jiangsu	10.3685	9.9083	6.0513	0.6779	0.6768	0.6213	0.6587	42
16	Jintan	Jiangsu	10.2659	10.5169	5.7310	0.6712	0.7183	0.5884	0.6593	41
17	Changshu	Jiangsu	11.4709	12.1705	7.2818	0.7500	0.8313	0.7477	0.7763	14
18	Zhangjiagang	Jiangsu	11.8391	11.9520	7.3800	0.7741	0.8164	0.7578	0.7827	12
19	Kunshan	Jiangsu	11.4089	12.7028	7.6498	0.7459	0.8676	0.7855	0.7997	11
20	Wujiang	Jiangsu	11.5058	12.3323	6.9111	0.7523	0.8423	0.7096	0.7681	15
21	Taicang	Jiangsu	0.0000	0.0000	6.5935	0.0000	0.0000	0.6770	0.2257	61
22	Rudong	Jiangsu	12.1096	12.4623	5.8647	0.7917	0.8512	0.6022	0.7484	21
23	Qidong	Jiangsu	10.5711	12.7596	6.0639	0.6912	0.8715	0.6226	0.7284	26
24	Rugao	Jiangsu	11.5364	10.0127	6.0661	0.7543	0.6839	0.6228	0.6870	35
25	Tongzhou	Jiangsu	12.1096	12.2473	6.2305	0.7917	0.8365	0.6397	0.7560	18
26	Haimen	Jiangsu	10.6260	11.5524	6.2148	0.6947	0.7891	0.6381	0.7073	31
27	Yangzhou	Jiangsu	12.9200	12.7244	6.8971	0.8447	0.8691	0.7082	0.8073	10
28	Yizheng	Jiangsu	10.2910	9.6193	5.6282	0.6728	0.6570	0.5779	0.6359	50
29	Jiangdu	Jiangsu	10.6174	10.4218	6.1855	0.6942	0.7118	0.6351	0.6804	37
30	Danyang	Jiangsu	10.7756	11.2468	6.4096	0.7045	0.7682	0.6581	0.7103	30
31	Yangzhong	Jiangsu	10.9469	11.0128	5.5093	0.7157	0.7522	0.5657	0.6779	38
32	Jurong	Jiangsu	10.2375	10.0775	5.4934	0.6693	0.6883	0.5640	0.6406	48
33	Taizhou	Jiangsu	12.3312	11.8605	6.3395	0.8062	0.8101	0.6509	0.7558	19
34	Jingjiang	Jiangsu	9.9843	9.3874	6.0890	0.6528	0.6412	0.6252	0.6397	49
35	Taixing	Jiangsu	9.3493	9.3926	6.0102	0.6113	0.6415	0.6171	0.6233	52
36	Jiangyan	Jiangsu	10.2004	10.3037	5.7261	0.6669	0.7038	0.5879	0.6529	43
37	Fuyang	Zhejiang	11.2418	11.5371	6.0299	0.7350	0.7880	0.6191	0.7141	29
38	Linan	Zhejiang	10.8715	10.7581	5.6618	0.7108	0.7348	0.5813	0.6756	39
39	Yuyao	Zhejiang	12.1502	12.3061	6.3419	0.7944	0.8405	0.6512	0.7620	16
40	Cixi	Zhejiang	11.5282	11.8712	6.6299	0.7537	0.8108	0.6807	0.7484	20
41	Xiucheng	Zhejiang	10.4371	9.9660	0.0000	0.6824	0.6807	0.0000	0.4544	59
42	Xiuzhou	Zhejiang	10.4660	10.0123	0.0000	0.6843	0.6839	0.0000	0.4561	58
43	Jiashan	Zhejiang	10.4400	9.9688	5.6208	0.6826	0.6809	0.5771	0.6469	45
44	Haiyan	Zhejiang	10.4282	9.9508	0.0000	0.6818	0.6797	0.0000	0.4538	60
45	Haining	Zhejiang	10.7715	11.0140	6.1221	0.7043	0.7523	0.6286	0.6950	33
46	Pinghu	Zhejiang	10.6386	10.3445	5.8305	0.6956	0.7066	0.5987	0.6669	40
47	Tongxiang	Zhejiang	10.1327	9.5474	6.0143	0.6625	0.6521	0.6175	0.6440	47
48	Huzhou	Zhejiang	11.1566	11.4120	6.3910	0.7294	0.7795	0.6562	0.7217	27
49	Deqing	Zhejiang	11.1422	11.4009	5.4813	0.7285	0.7787	0.5628	0.6900	34
50	Changxing	Zhejiang	11.1287	11.3908	5.6487	0.7276	0.7780	0.5800	0.6952	32
51	Anji	Zhejiang	11.1433	11.4020	5.2477	0.7286	0.7788	0.5388	0.6821	36
52	Shangyu	Zhejiang	11.3332	11.6174	6.0782	0.7410	0.7935	0.6241	0.7195	28
53	Wuhu	Anhui	13.5516	13.5144	4.6347	0.8860	0.9231	0.4759	0.7617	17
54	Xiangshan	Anhui	12.6012	11.8307	0.0000	0.8239	0.8081	0.0000	0.5440	57
55	Dangtu	Anhui	12.5968	12.5238	5.2439	0.8236	0.8554	0.5384	0.7391	24
56	Xuancheng	Anhui	10.8784	10.4654	4.9940	0.7112	0.7148	0.5128	0.6463	46
57	Langxi	Anhui	10.6485	10.4513	4.0502	0.6962	0.7139	0.4159	0.6086	53
58	Guangde	Anhui	10.6053	10.4049	4.5985	0.6934	0.7107	0.4722	0.6254	51
59	Jingxian	Anhui	10.6349	10.4826	3.8459	0.6953	0.7160	0.3949	0.6021	54
60	Jixi	Anhui	10.6638	10.5192	3.5098	0.6972	0.7185	0.3604	0.5920	55
61	Jingde	Anhui	10.5921	10.3890	3.0131	0.6925	0.7096	0.3094	0.5705	56
62	Ningguo	Anhui	11.1098	10.5026	4.8686	0.7264	0.7174	0.4999	0.6479	44

Table 6. Economic performance normalizations, scores, and rankings, 2010.

iii. Baseline 3. Cultural Amenity

The variables concerned with cultural amenities were represented in the ArcGIS map of the Changjiang Delta Region. These maps included cultural heritage and tourist destinations, state-level scenic spots and historic sites, public recreational green space, numbers of parks, and urban landscape and park areas. Together with the Cultural Amenity Index, they revealed basic cultural amenity conditions of the Changjiang Delta Region in 2010.

Cultural heritage and tourist destinations were defined by the frequency of trips traveled to the cities, influence of destination choice for short and long term holidays, and rankings from a variety of travel websites. The results showed the top destinations in red and others in white. A quick visual inspection revealed that large cities and around the Lake Tai area were the major cultural heritage places.

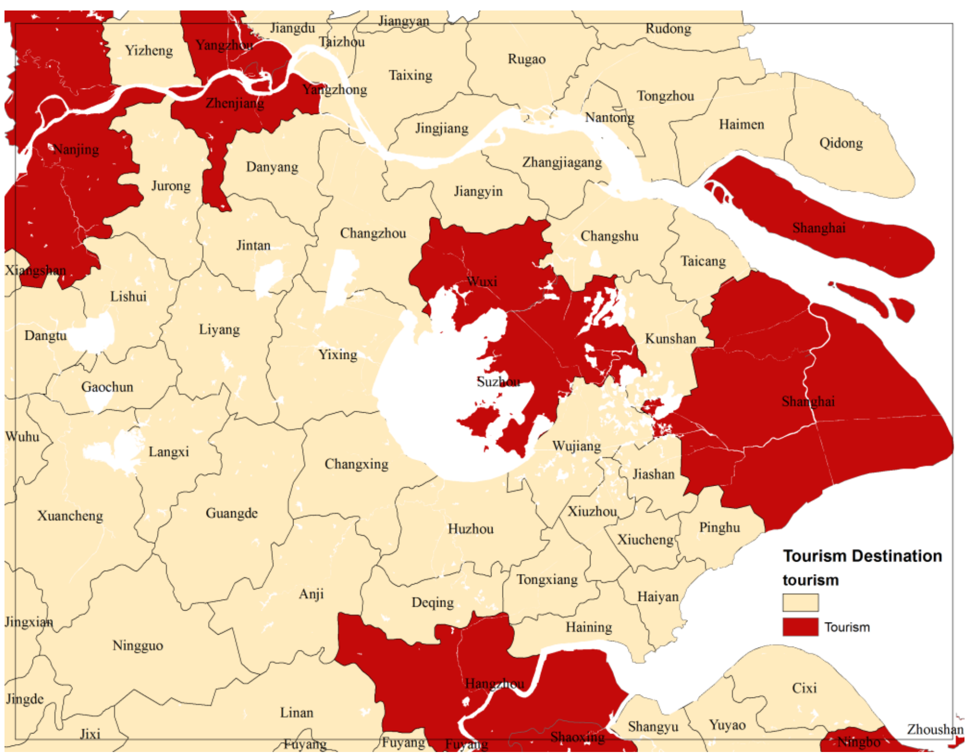


Figure 55. Cultural heritage and tourism destination spatial distribution in the Changjiang Delta Region, 2010.

The state-level scenic spots and historic sites were selected based on state government definitions. On one side, they are on the top list of historical preservation with constrains attached to limit development in certain areas, on the other side they enjoy favorable policies from the central government to attract investment of urban construction. The results were classified with natural breaks of five categories. A quick visual inspection revealed that Shanghai, Nanjing, and Hangzhou composed the tripod of the region with some high value north of Lake Tai, such as Suzhou.

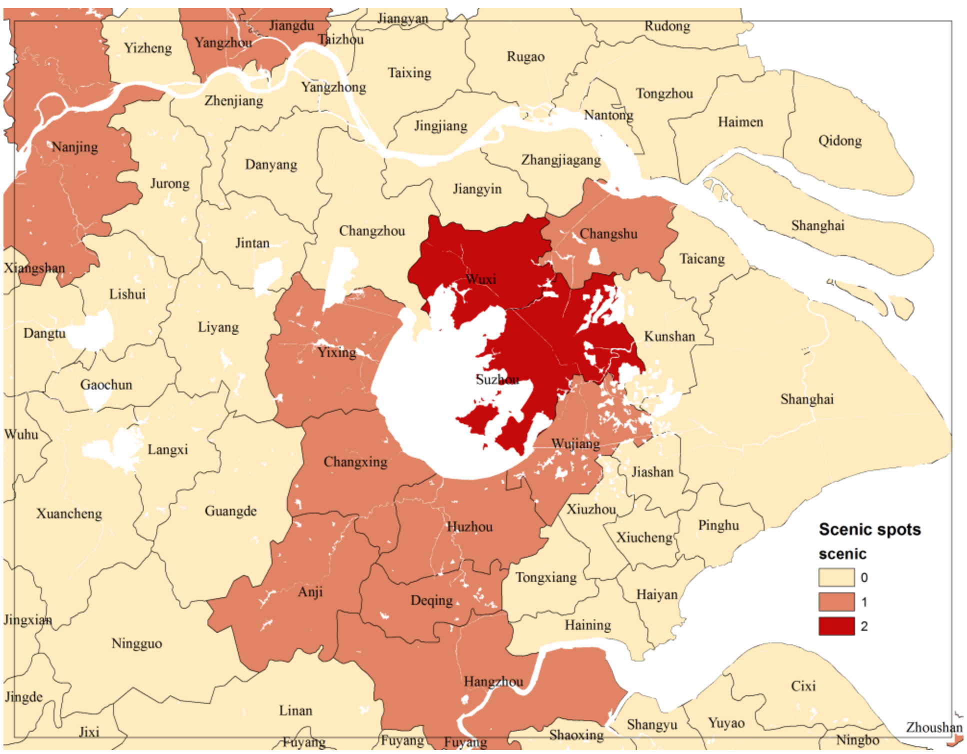


Figure 56. State-level scenic spots and historic sites spatial distribution in the Changjiang Delta Region, 2010.

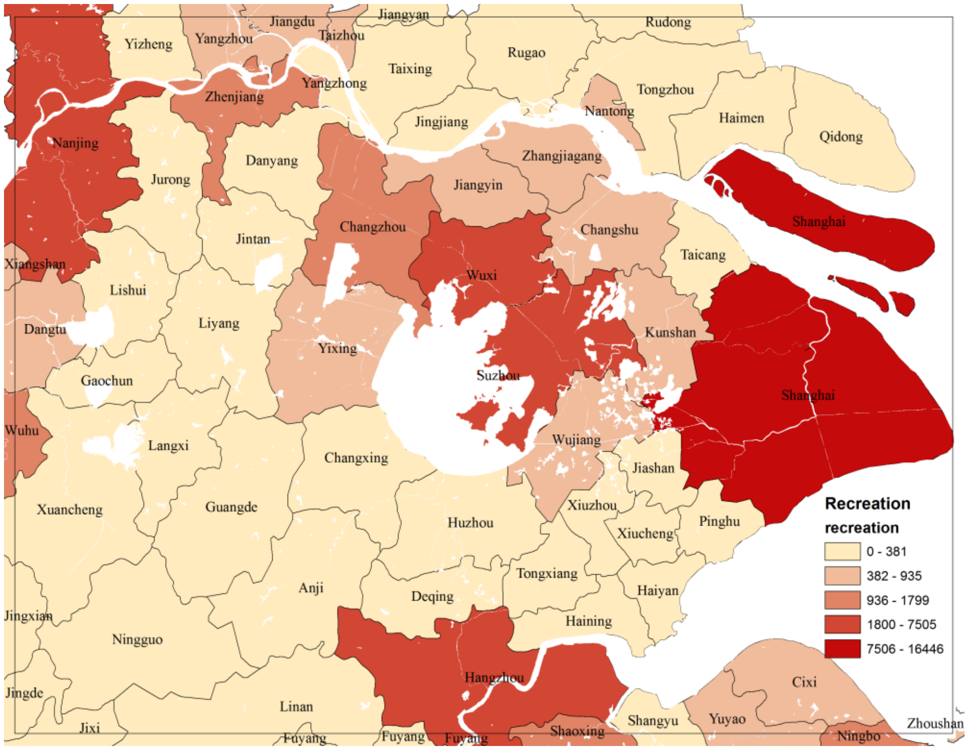


Figure 57. Public recreational green space spatial distribution in the Changjiang Delta Region, 2010.

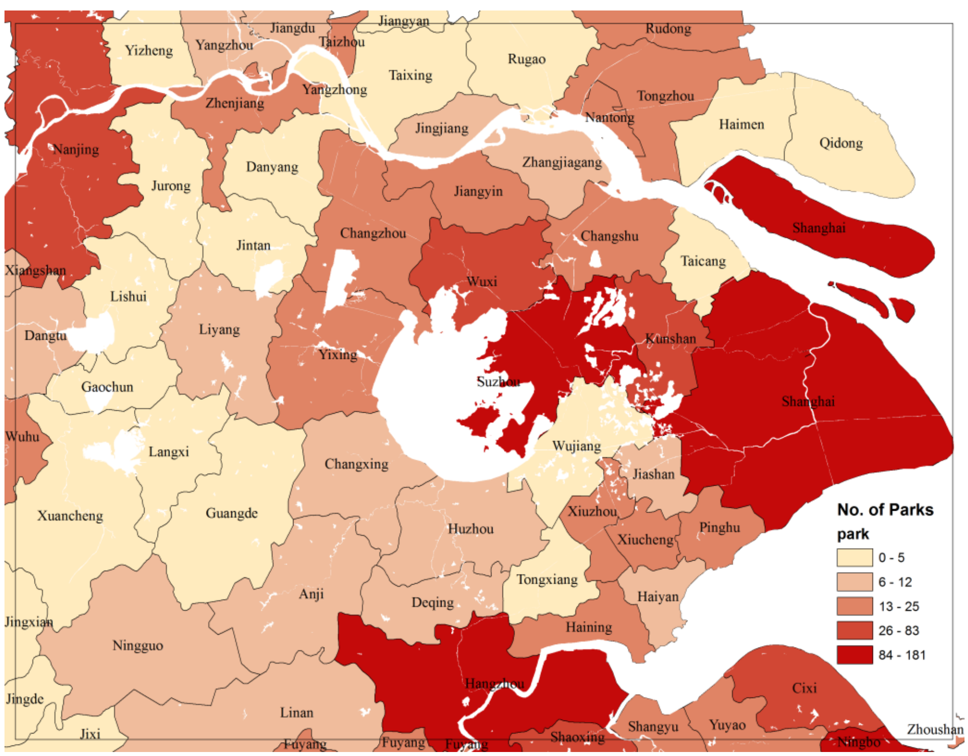


Figure 58a. Number of parks spatial distribution in the Changjiang Delta Region, 2010.

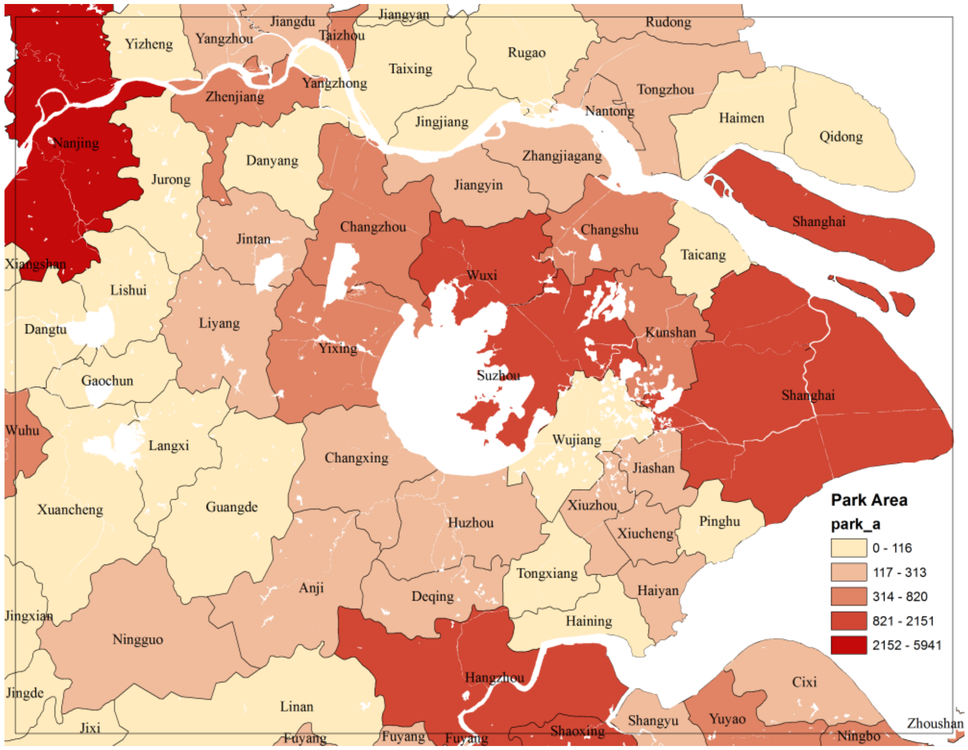


Figure 58b. Urban landscape and park area spatial distribution in the Changjiang Delta Region, 2010.

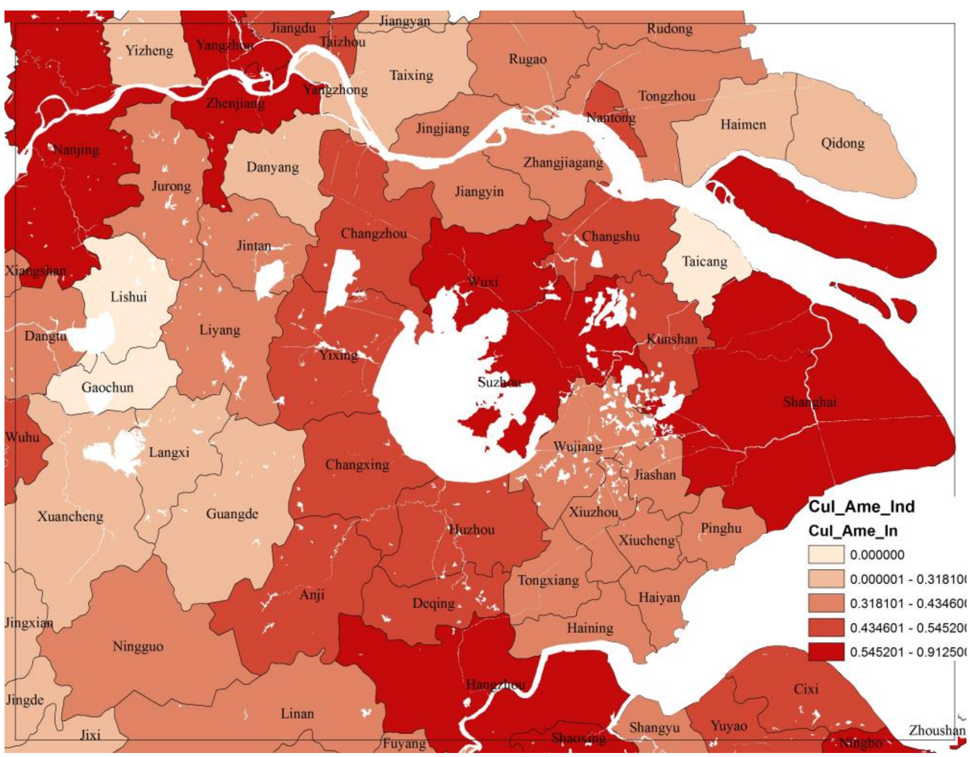


Figure 59. Cultural Amenity Index spatial distribution in the Changjiang Delta Region, 2010.

FID	City	Province	Cultural Heritage and Tourist Destination	State-Level Scenic Spots and Historic Sites	Area of Public Recreational Green Space (Hectare)	Number of Parks	Urban Landscape and Park Area
0	Zhoushan	Zhejiang	Yes	1	688	16	421
1	Wuxi	Jiangsu	Yes	2	3,485	38	1,290
2	Changzhou	Jiangsu	N	0	1,704	25	520
3	Shanghai	Shanghai	Yes	0	16,446	153	2,151
4	Ningbo	Zhejiang	Yes	0	1,799	114	820
5	Suzhou	Jiangsu	Yes	2	3,662	152	1,845
6	Zhenjiang	Jiangsu	Yes	0	1,445	17	598
7	Nanjing	Jiangsu	Yes	1	7,505	83	5,941
8	Nantong	Jiangsu	N	0	657	19	235
9	Hangzhou	Zhejiang	Yes	1	5,287	181	2,047
10	Shaoxing	Zhejiang	Yes	0	1,129	41	2,078
11	Lishui	Jiangsu	N	0	0	0	0
12	Gaochun	Jiangsu	N	0	0	0	0
13	Jiangyin	Jiangsu	N	0	492	15	223
14	Yixing	Jiangsu	N	1	748	15	358
15	Liyang	Jiangsu	N	0	181	6	128
16	Jintan	Jiangsu	N	0	212	5	128
17	Changshu	Jiangsu	N	1	781	13	546
18	Zhangjiagang	Jiangsu	N	0	552	8	313
19	Kunshan	Jiangsu	N	0	460	59	495
20	Wujiang	Jiangsu	N	1	551	2	38
21	Taicang	Jiangsu	N	0	0	0	0
22	Rudong	Jiangsu	N	0	257	19	235
23	Qidong	Jiangsu	N	0	125	5	55
24	Rugao	Jiangsu	N	0	220	4	106
25	Tongzhou	Jiangsu	N	0	357	19	235
26	Haimen	Jiangsu	N	0	129	1	9
27	Yangzhou	Jiangsu	Yes	1	935	9	262
28	Yizheng	Jiangsu	N	0	182	3	37
29	Jiangdu	Jiangsu	N	1	935	9	262
30	Danyang	Jiangsu	N	0	331	3	34
31	Yangzhong	Jiangsu	N	0	136	4	40
32	Jurong	Jiangsu	N	0	173	4	116
33	Taizhou	Jiangsu	N	0	602	13	379
34	Jingjiang	Jiangsu	N	0	293	6	84
35	Taixing	Jiangsu	N	0	205	4	36
36	Jiangyan	Jiangsu	N	0	162	3	29
37	Fuyang	Zhejiang	N	0	222	13	139
38	Linan	Zhejiang	N	0	182	9	76
39	Yuyao	Zhejiang	N	0	433	22	401
40	Cixi	Zhejiang	N	0	627	39	130
41	Xiucheng	Zhejiang	N	0	298	15	210
42	Xiuzhou	Zhejiang	N	0	278	15	200
43	Jiashan	Zhejiang	N	0	190	12	198
44	Haiyan	Zhejiang	N	0	210	9	190
45	Haining	Zhejiang	N	0	211	14	77
46	Pinghu	Zhejiang	N	0	187	13	110
47	Tongxiang	Zhejiang	N	0	278	5	66
48	Huzhou	Zhejiang	N	1	380	12	202
49	Deqing	Zhejiang	N	1	320	10	190
50	Changxing	Zhejiang	N	1	381	10	162
51	Anji	Zhejiang	N	1	300	9	208
52	Shangyu	Zhejiang	N	0	259	16	138
53	Wuhu	Anhui	N	0	1,495	14	602
54	Xiangshan	Anhui	N	0	471	6	80
55	Dangtu	Anhui	N	0	470	6	79
56	Xuancheng	Anhui	N	0	68	2	69
57	Langxi	Anhui	N	0	50	2	52
58	Guangde	Anhui	N	0	57	1	55
59	Jingxian	Anhui	N	0	48	1	67
60	Jixi	Anhui	N	0	51	1	53
61	Jingde	Anhui	N	0	61	1	63
62	Ningguo	Anhui	N	0	190	9	197

Table 7. Baseline 3: cultural amenities variables and data collections, 2010.

FID	City	Province	Natural Logarithm of Area of Public Recreational Green Space	Standard Deviation of Public Recreational Green Space	Normalizing Public Recreational Green Space by Scaling Between 0 and 1	Natural Logarithm of Number of Parks	Standard Deviation of Number of Parks	Normalizing Number of Parks by Scaling Between 0 and 1	Natural Logarithm of Urban Landscape and Park Area	Standard Deviation of Urban Landscape and Park Area	Normalizing Urban Landscape and Park Area by Scaling Between 0 and 1
0	Zhoushan	Zhejiang	6.5338	0.4444	0.6730	2.7726	0.4310	0.5333	6.0426	0.6266	0.6954
1	Wuxi	Jiangsu	8.1562	1.3831	0.8402	3.6376	1.0961	0.6997	7.1624	1.3130	0.8242
2	Changzhou	Jiangsu	7.4407	0.9691	0.7665	3.2189	0.7742	0.6192	6.2538	0.7560	0.7197
3	Shanghai	Shanghai	9.7078	2.2810	1.0000	5.0304	2.1671	0.9677	7.6737	1.6264	0.8831
4	Ningbo	Zhejiang	7.4950	1.0005	0.7721	4.7362	1.9409	0.9111	6.7093	1.0352	0.7721
5	Suzhou	Jiangsu	8.2058	1.4118	0.8453	5.0239	2.1621	0.9664	7.5202	1.5323	0.8654
6	Zhenjiang	Jiangsu	7.2759	0.8737	0.7495	2.8332	0.4776	0.5450	6.3936	0.8417	0.7358
7	Nanjing	Jiangsu	8.9233	1.8270	0.9192	4.4188	1.6969	0.8500	8.6896	2.2491	1.0000
8	Nantong	Jiangsu	6.4877	0.4177	0.6683	2.9444	0.5632	0.5664	5.4596	0.2692	0.6283
9	Hangzhou	Zhejiang	8.5730	1.6243	0.8831	5.1985	2.2964	1.0000	7.6241	1.5960	0.8774
10	Shaoxing	Zhejiang	7.0291	0.7310	0.7241	3.7136	1.1546	0.7144	7.6392	1.6052	0.8791
11	Lishui	Jiangsu	0.0000	-3.3363	0.0000	0.0000	-1.7009	0.0000	0.0000	-3.0774	0.0000
12	Gaochun	Jiangsu	0.0000	-3.3363	0.0000	0.0000	-1.7009	0.0000	0.0000	-3.0774	0.0000
13	Jiangyin	Jiangsu	6.1985	0.2503	0.6385	2.7081	0.3814	0.5209	5.4072	0.2370	0.6223
14	Yixing	Jiangsu	6.6174	0.4927	0.6817	2.7081	0.3814	0.5209	5.8805	0.5272	0.6767
15	Liyang	Jiangsu	5.1985	-0.3283	0.5355	1.7918	-0.3231	0.3447	4.8520	-0.1032	0.5584
16	Jintan	Jiangsu	5.3566	-0.2368	0.5518	1.6094	-0.4633	0.3096	4.8520	-0.1032	0.5584
17	Changshu	Jiangsu	6.6606	0.5177	0.6861	2.5649	0.2714	0.4934	6.3026	0.7859	0.7253
18	Zhangjiagang	Jiangsu	6.3135	0.3169	0.6504	2.0794	-0.1019	0.4000	5.7462	0.4449	0.6613
19	Kunshan	Jiangsu	6.1312	0.2114	0.6316	4.0775	1.4344	0.7844	6.2046	0.7258	0.7140
20	Wujiang	Jiangsu	6.3117	0.3159	0.6502	0.6931	-1.1679	0.1333	3.6376	-0.8477	0.4186
21	Taicang	Jiangsu	0.0000	-3.3363	0.0000	0.0000	-1.7009	0.0000	0.0000	-3.0774	0.0000
22	Rudong	Jiangsu	5.5491	-0.1254	0.5716	2.9444	0.5632	0.5664	5.4596	0.2692	0.6283
23	Qidong	Jiangsu	4.8283	-0.5425	0.4974	1.6094	-0.4633	0.3096	4.0073	-0.6210	0.4612
24	Rugao	Jiangsu	5.3936	-0.2154	0.5556	1.3863	-0.6349	0.2667	4.6634	-0.2188	0.5367
25	Tongzhou	Jiangsu	5.8777	0.0647	0.6055	2.9444	0.5632	0.5664	5.4596	0.2692	0.6283
26	Haimen	Jiangsu	4.8598	-0.5243	0.5006	0.0000	-1.7009	0.0000	2.1972	-1.7306	0.2529
27	Yangzhou	Jiangsu	6.8405	0.6219	0.7046	2.1972	-0.0114	0.4227	5.5683	0.3358	0.6408
28	Yizheng	Jiangsu	5.2040	-0.3251	0.5361	1.0986	-0.8561	0.2113	3.6109	-0.8640	0.4155
29	Jiangdu	Jiangsu	6.8405	0.6219	0.7046	2.1972	-0.0114	0.4227	5.5683	0.3358	0.6408
30	Danyang	Jiangsu	5.8021	0.0210	0.5977	1.0986	-0.8561	0.2113	3.5264	-0.9158	0.4058
31	Yangzhong	Jiangsu	4.9127	-0.4937	0.5061	1.3863	-0.6349	0.2667	3.6889	-0.8162	0.4245
32	Jurong	Jiangsu	5.1533	-0.3544	0.5308	1.3863	-0.6349	0.2667	4.7536	-0.1636	0.5470
33	Taizhou	Jiangsu	6.4003	0.3671	0.6593	2.5649	0.2714	0.4934	5.9375	0.5621	0.6833
34	Jingjiang	Jiangsu	5.6802	-0.0496	0.5851	1.7918	-0.3231	0.3447	4.4308	-0.3614	0.5099
35	Taixing	Jiangsu	5.3230	-0.2562	0.5483	1.3863	-0.6349	0.2667	3.5835	-0.8808	0.4124
36	Jiangyan	Jiangsu	5.0876	-0.3924	0.5241	1.0986	-0.8561	0.2113	3.3673	-1.0134	0.3875
37	Fuyang	Zhejiang	5.4027	-0.2101	0.5565	2.5649	0.2714	0.4934	4.9345	-0.0527	0.5679
38	Linan	Zhejiang	5.2040	-0.3251	0.5361	2.1972	-0.0114	0.4227	4.3307	-0.4228	0.4984
39	Yuyao	Zhejiang	6.0707	0.1764	0.6253	3.0910	0.6759	0.5946	5.9940	0.5967	0.6898
40	Cixi	Zhejiang	6.4409	0.3906	0.6635	3.6636	1.1161	0.7047	4.8675	-0.0937	0.5602
41	Xiucheng	Zhejiang	5.6971	-0.0398	0.5869	2.7081	0.3814	0.5209	5.3471	0.2002	0.6153
42	Xiuzhou	Zhejiang	5.6276	-0.0800	0.5797	2.7081	0.3814	0.5209	5.2983	0.1703	0.6097
43	Jiashan	Zhejiang	5.2470	-0.3002	0.5405	2.4849	0.2098	0.4780	5.2883	0.1642	0.6086
44	Haiyan	Zhejiang	5.3471	-0.2423	0.5508	2.1972	-0.0114	0.4227	5.2470	0.1389	0.6038
45	Haining	Zhejiang	5.3519	-0.2395	0.5513	2.6391	0.3284	0.5077	4.3438	-0.4148	0.4999
46	Pinghu	Zhejiang	5.2311	-0.3094	0.5389	2.5649	0.2714	0.4934	4.7005	-0.1961	0.5409
47	Tongxiang	Zhejiang	5.6276	-0.0800	0.5797	1.6094	-0.4633	0.3096	4.1897	-0.5093	0.4821
48	Huzhou	Zhejiang	5.9402	0.1009	0.6119	2.4849	0.2098	0.4780	5.3083	0.1764	0.6109
49	Deqing	Zhejiang	5.7683	0.0014	0.5942	2.3026	0.0696	0.4429	5.2470	0.1389	0.6038
50	Changxing	Zhejiang	5.9428	0.1024	0.6122	2.3026	0.0696	0.4429	5.0876	0.0412	0.5855
51	Anji	Zhejiang	5.7038	-0.0359	0.5875	2.1972	-0.0114	0.4227	5.3375	0.1944	0.6142
52	Shangyu	Zhejiang	5.5568	-0.1209	0.5724	2.7726	0.4310	0.5333	4.9273	-0.0571	0.5670
53	Wuhu	Anhui	7.3099	0.8934	0.7530	2.6391	0.3284	0.5077	6.4003	0.8458	0.7365
54	Xiangshan	Anhui	6.1549	0.2251	0.6340	1.7918	-0.3231	0.3447	4.3820	-0.3913	0.5043
55	Dangtu	Anhui	6.1527	0.2239	0.6338	1.7918	-0.3231	0.3447	4.3694	-0.3991	0.5028
56	Xuancheng	Anhui	4.2195	-0.8948	0.4346	0.6931	-1.1679	0.1333	4.2341	-0.4820	0.4873
57	Langxi	Anhui	3.9120	-1.0727	0.4030	0.6931	-1.1679	0.1333	3.9512	-0.6554	0.4547
58	Guangde	Anhui	4.0431	-0.9969	0.4165	0.0000	-1.7009	0.0000	4.0073	-0.6210	0.4612
59	Jingxian	Anhui	3.8712	-1.0963	0.3988	0.0000	-1.7009	0.0000	4.2047	-0.5000	0.4839
60	Jixi	Anhui	3.9318	-1.0612	0.4050	0.0000	-1.7009	0.0000	3.9703	-0.6437	0.4569
61	Jingde	Anhui	4.1109	-0.9576	0.4235	0.0000	-1.7009	0.0000	4.1431	-0.5378	0.4768
62	Ningguo	Anhui	5.2470	-0.3002	0.5405	2.1972	-0.0114	0.4227	5.2832	0.1611	0.6080

Table 8. Baseline 3: cultural amenity data normalizations, 2010.

FID	City	Province	Weighted Cultrual Heritage and Tourist Destination	Weighted State-Level Scenic Spot and Historic Sites	Weighted Public Recreational Green Space	Weighted Number of Parks	Urban Landscape and Park Area by Scaling Between 0 and	Score	Rank
0	Zhoushan	Zhejiang	0.5000	0.2500	0.6730	0.2667	0.6954	2.3851	8
1	Wuxi	Jiangsu	0.5000	0.5000	0.8402	0.3499	0.8242	3.0143	3
2	Changzhou	Jiangsu	0.0000	0.0000	0.7665	0.3096	0.7197	1.7958	14
3	Shanghai	Shanghai	0.5000	0.0000	1.0000	0.4838	0.8831	2.8669	5
4	Ningbo	Zhejiang	0.5000	0.0000	0.7721	0.4555	0.7721	2.4997	6
5	Suzhou	Jiangsu	0.5000	0.5000	0.8453	0.4832	0.8654	3.1939	1
6	Zhenjiang	Jiangsu	0.5000	0.0000	0.7495	0.2725	0.7358	2.2578	10
7	Nanjing	Jiangsu	0.5000	0.2500	0.9192	0.4250	1.0000	3.0942	2
8	Nantong	Jiangsu	0.0000	0.0000	0.6683	0.2832	0.6283	1.5798	23
9	Hangzhou	Zhejiang	0.5000	0.2500	0.8831	0.5000	0.8774	3.0105	4
10	Shaoxing	Zhejiang	0.5000	0.0000	0.7241	0.3572	0.8791	2.4604	7
11	Lishui	Jiangsu	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	62
12	Gaochun	Jiangsu	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	62
13	Jiangyin	Jiangsu	0.0000	0.0000	0.6385	0.2605	0.6223	1.5212	25
14	Yixing	Jiangsu	0.0000	0.2500	0.6817	0.2605	0.6767	1.8689	12
15	Liyang	Jiangsu	0.0000	0.0000	0.5355	0.1723	0.5584	1.2662	42
16	Jintan	Jiangsu	0.0000	0.0000	0.5518	0.1548	0.5584	1.2649	43
17	Changshu	Jiangsu	0.0000	0.2500	0.6861	0.2467	0.7253	1.9081	11
18	Zhangjiagang	Jiangsu	0.0000	0.0000	0.6504	0.2000	0.6613	1.5116	27
19	Kunshan	Jiangsu	0.0000	0.0000	0.6316	0.3922	0.7140	1.7378	16
20	Wujiang	Jiangsu	0.0000	0.2500	0.6502	0.0667	0.4186	1.3854	33
21	Taicang	Jiangsu	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	62
22	Rudong	Jiangsu	0.0000	0.0000	0.5716	0.2832	0.6283	1.4831	28
23	Qidong	Jiangsu	0.0000	0.0000	0.4974	0.1548	0.4612	1.1133	48
24	Rugao	Jiangsu	0.0000	0.0000	0.5556	0.1333	0.5367	1.2256	45
25	Tongzhou	Jiangsu	0.0000	0.0000	0.6055	0.2832	0.6283	1.5170	26
26	Haimen	Jiangsu	0.0000	0.0000	0.5006	0.0000	0.2529	0.7535	60
27	Yangzhou	Jiangsu	0.5000	0.2500	0.7046	0.2113	0.6408	2.3068	9
28	Yizheng	Jiangsu	0.0000	0.0000	0.5361	0.1057	0.4155	1.0573	52
29	Jiangdu	Jiangsu	0.0000	0.2500	0.7046	0.2113	0.6408	1.8068	13
30	Danyang	Jiangsu	0.0000	0.0000	0.5977	0.1057	0.4058	1.1092	49
31	Yangzhong	Jiangsu	0.0000	0.0000	0.5061	0.1333	0.4245	1.0639	51
32	Jurong	Jiangsu	0.0000	0.0000	0.5308	0.1333	0.5470	1.2112	47
33	Taizhou	Jiangsu	0.0000	0.0000	0.6593	0.2467	0.6833	1.5893	22
34	Jingjiang	Jiangsu	0.0000	0.0000	0.5851	0.1723	0.5099	1.2673	41
35	Taixing	Jiangsu	0.0000	0.0000	0.5483	0.1333	0.4124	1.0940	50
36	Jiangyan	Jiangsu	0.0000	0.0000	0.5241	0.1057	0.3875	1.0172	53
37	Fuyang	Zhejiang	0.0000	0.0000	0.5565	0.2467	0.5679	1.3711	34
38	Linan	Zhejiang	0.0000	0.0000	0.5361	0.2113	0.4984	1.2458	44
39	Yuyao	Zhejiang	0.0000	0.0000	0.6253	0.2973	0.6898	1.6124	21
40	Cixi	Zhejiang	0.0000	0.0000	0.6635	0.3524	0.5602	1.5760	24
41	Xiucheng	Zhejiang	0.0000	0.0000	0.5869	0.2605	0.6153	1.4627	29
42	Xiuzhou	Zhejiang	0.0000	0.0000	0.5797	0.2605	0.6097	1.4499	30
43	Jiashan	Zhejiang	0.0000	0.0000	0.5405	0.2390	0.6086	1.3881	32
44	Haiyan	Zhejiang	0.0000	0.0000	0.5508	0.2113	0.6038	1.3660	35
45	Haining	Zhejiang	0.0000	0.0000	0.5513	0.2538	0.4999	1.3050	40
46	Pinghu	Zhejiang	0.0000	0.0000	0.5389	0.2467	0.5409	1.3265	37
47	Tongxiang	Zhejiang	0.0000	0.0000	0.5797	0.1548	0.4821	1.2166	46
48	Huzhou	Zhejiang	0.0000	0.2500	0.6119	0.2390	0.6109	1.7118	17
49	Deqing	Zhejiang	0.0000	0.2500	0.5942	0.2215	0.6038	1.6695	18
50	Changxing	Zhejiang	0.0000	0.2500	0.6122	0.2215	0.5855	1.6691	19
51	Anji	Zhejiang	0.0000	0.2500	0.5875	0.2113	0.6142	1.6631	20
52	Shangyu	Zhejiang	0.0000	0.0000	0.5724	0.2667	0.5670	1.4061	31
53	Wuhu	Anhui	0.0000	0.0000	0.7530	0.2538	0.7365	1.7434	15
54	Xiangshan	Anhui	0.0000	0.0000	0.6340	0.1723	0.5043	1.3106	38
55	Dangtu	Anhui	0.0000	0.0000	0.6338	0.1723	0.5028	1.3090	39
56	Xuancheng	Anhui	0.0000	0.0000	0.4346	0.0667	0.4873	0.9886	54
57	Langxi	Anhui	0.0000	0.0000	0.4030	0.0667	0.4547	0.9244	55
58	Guangde	Anhui	0.0000	0.0000	0.4165	0.0000	0.4612	0.8776	58
59	Jingxian	Anhui	0.0000	0.0000	0.3988	0.0000	0.4839	0.8826	57
60	Jixi	Anhui	0.0000	0.0000	0.4050	0.0000	0.4569	0.8619	59
61	Jingde	Anhui	0.0000	0.0000	0.4235	0.0000	0.4768	0.9002	56
62	Ningguo	Anhui	0.0000	0.0000	0.5405	0.2113	0.6080	1.3598	36

Table 9. Baseline 3: cultural amenity scores and rankings, 2010.

6. Evaluations of the selected scenarios using baseline conditions for comparisons and measurements.

a. Baseline 1: Environmental suitability and the projections of four selected scenarios.

Environmental suitability is relevant in contemporary circumstances of urban growth modelling such as in the Changjiang Delta Region. From the 2000s, both central and local governmental policies started to emphasize this measure, meaning the study of environmental suitability can be used to shape and to produce more efficient and well-organized urban forms which are responsible to underlying environmental conditions.

The purpose of comparing environmental suitability and the selected scenarios was to evaluate the influence of urban policies on the environment. The scenarios represented a specific predetermined policy that guides future urban growth. If the policy leads to an increasing encroachment of urbanization on environmentally sensitive land, then it should be reevaluated before implementation. In any event the model provides quantitative evidence supporting, or not, a policy regarding environmental concerns.

i. Baseline 1: environmental suitability vs. scenario 1: development corridors.

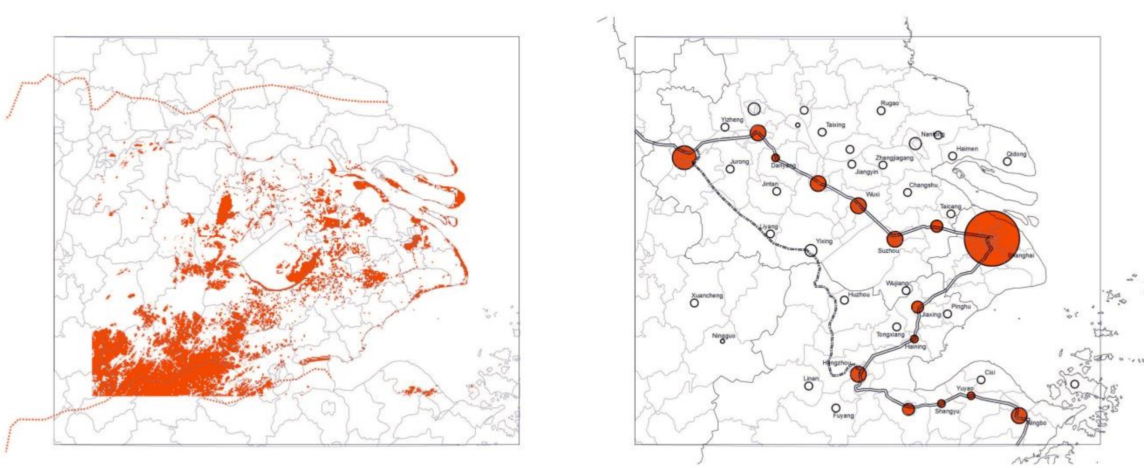


Figure 60. Environmental unsuitable areas (left) and development corridors (right), 2010.

The base maps of environmental suitability and the development corridors are shown in Figure 60. In the image to the left, the environmentally unsuitable areas are represented in red cells. The two curved lines in red are the boundaries of a regional watershed which enclosed most of the study areas. In the image to the right, the two existing development corridors are shown in solid black lines and the future development corridor in a dashed black line. The major cities situated along the development corridors are highlighted with red color.

The results from the Scenario Cellular Automata model predictions of annual growth and environmentally unsuitable development maps were drawn in Figure 61a. The black cells represent the urbanized land, the red cells are where unsuitable growth occurred, the green cells are the protected forest areas, and the blue cells are water. The buffer zone, which was created to avoid significant impact from neighboring large cities, was also represented in Figure 61b for two selected years, 2011 and 2030. The individual maps of interim years are reproduced in Appendix 2 'Scenario 1: development corridors model prediction and analysis for the Changjiang Delta Region'.

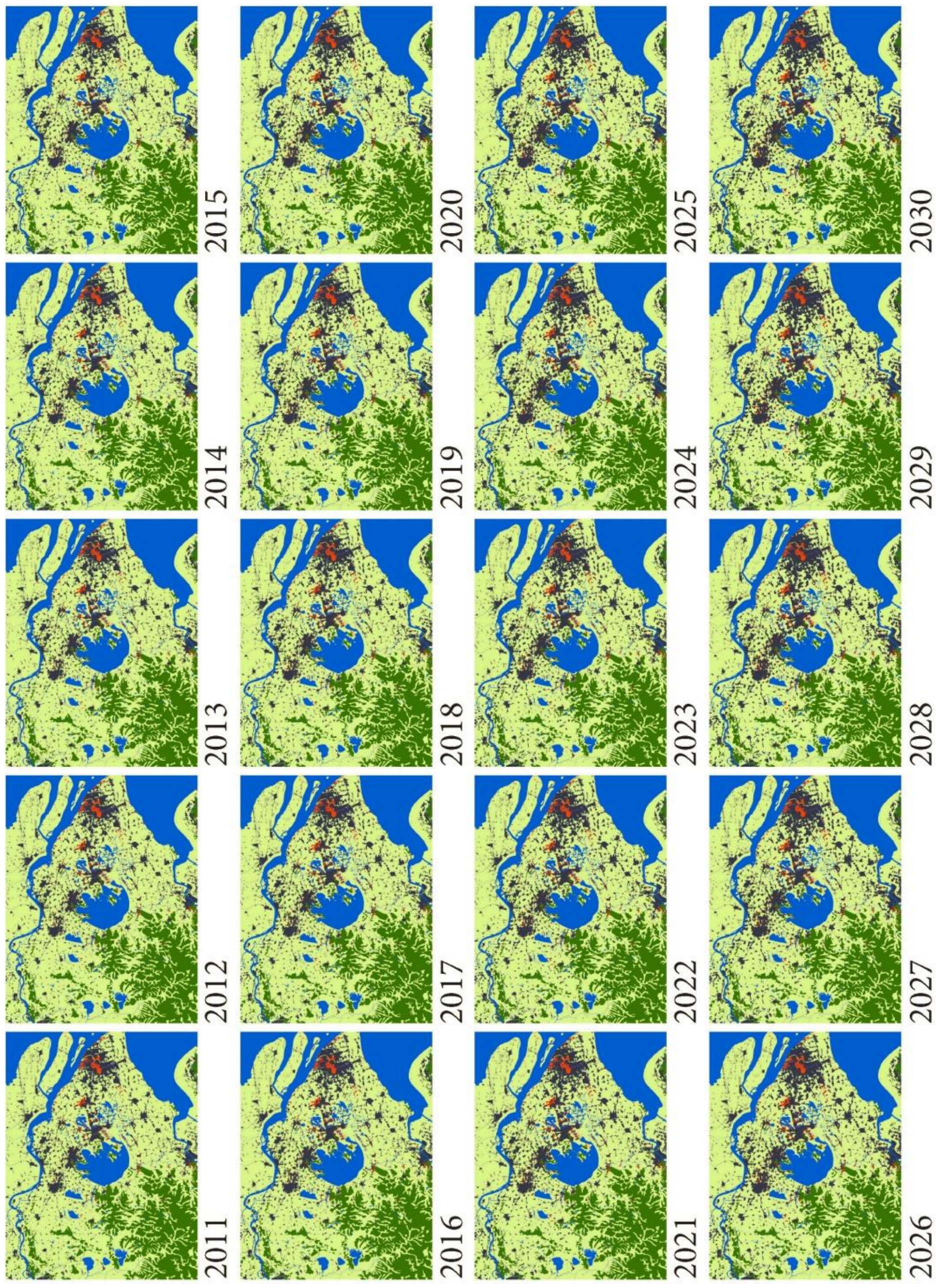


Figure 61a. Annual growth prediction and environmental unsuitable development, 2011-2030, baseline1: environmental suitability vs. scenario 1: development corridors.

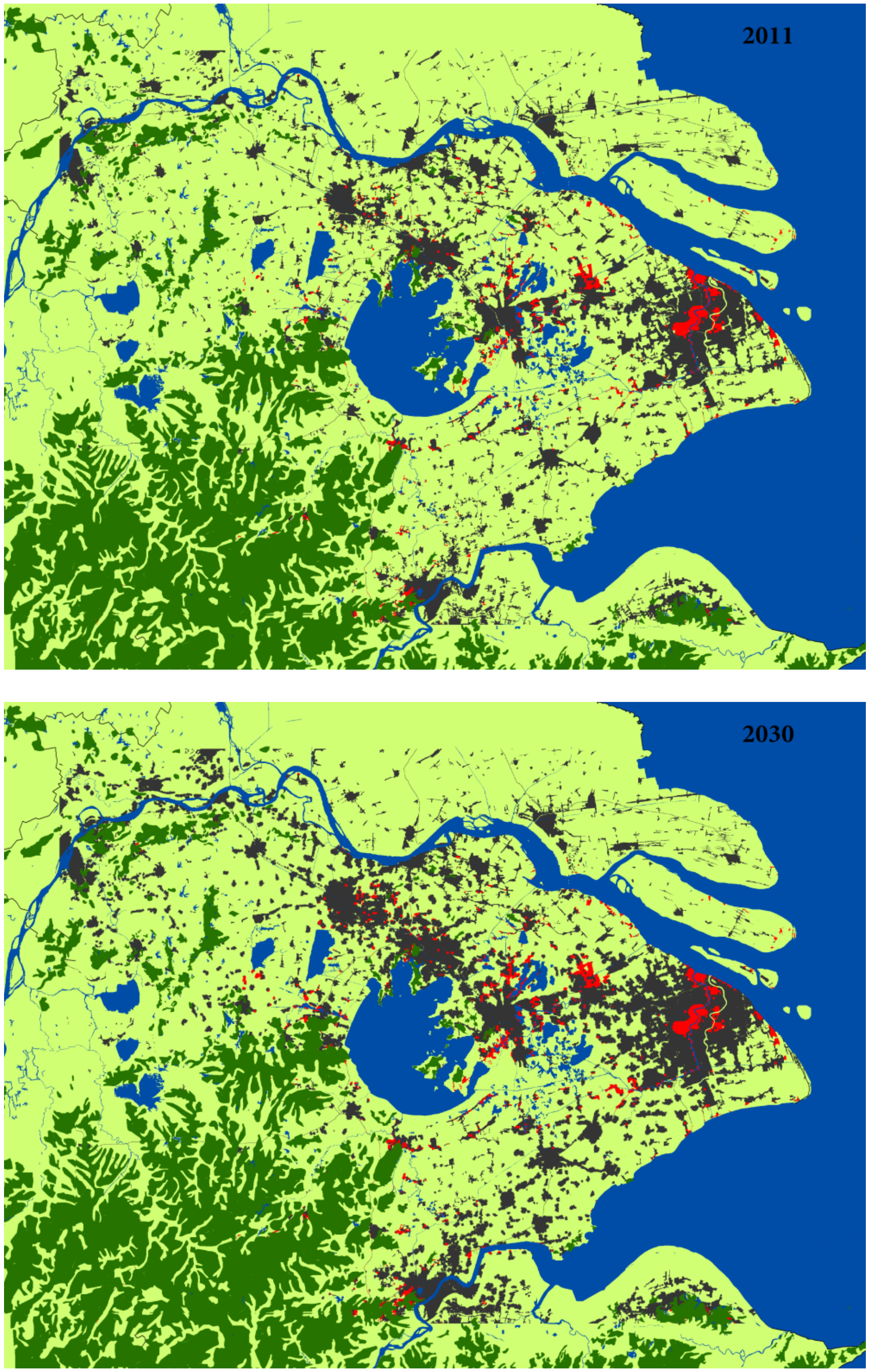


Figure 61b. Scenario Cellular Automata model predicted urban growth map with buffer zone around study area, 2010 (upper) and 2030 (lower), baseline1: environmental suitability vs. scenario 1: development corridors.

The results are summarized in Table 10. The number of grid cells in an urbanized area was first counted by year from 2011 to 2030. Then the number of grid cells in suitable areas was deducted from the urbanized area for each year. The results, hence, were the number of cells in unsuitable areas for the model prediction duration, listed in column ‘Number of cells in unsuitable area’. These numbers were then divided by the total number of grid cells of the entire study region. This result is shown in column ‘Urbanization rate based on land area’. These numbers are different from the urbanization rate of population, which are commonly used as a standard for evaluation of urban conditions internationally.

One of the outcomes was the ‘Percentage of urban development in unsuitable area’, which revealed a decreasing trend of urban development in unsuitable areas overall. Basically, if urban growth were constrained to the development corridors, the rate of urbanization in environmentally sensitive area would drop from 10.45% in 2011 to 10.05% in 2030. By emphasizing urban growth in the development corridors, the outcome of the urbanization pattern started to evolve in a more environmentally sensitive direction. The explanations were two-fold. First, the rate of growth in environmentally-suitable areas is higher than in unsuitable areas. Second, the current development corridors are in areas away from the major environmental protection zones. However, this is not to say that the environmental unsuitable areas will not be urbanized further. On the contrary, there was an increasing rate of urban growth encroaching environmental sensitive area from 2011 peaking in 2022, before a sharp drop from 2022 to 2024 followed by a moderate decrease from 2024 to 2030 (Figure 62). In the long term, the growth policy focusing around the development corridors could improve the urbanization outcome regarding environmental suitability. However, in the short term, other measures should be considered to dampen the increasing year-to-year growth of urbanization in unsuitable areas.

Table 10. Environmental suitability and development corridors.

Year	Scenario 1: Development Corridor					
	Number of Cells in Unsuitable Area	Number of Cells in Suitable Area	Number of Cells in Urbanized Area	Urbanization Rate based on Land Area	Percentage of Urban Development in Unsuitable Area	Year to Year Growth Rate of Unsuitable Area
2011	102,422	877,973	980,395	15.077%	10.447%	-
2012	103,747	891,530	995,277	15.306%	10.424%	1.294%
2013	105,086	905,567	1,010,653	15.542%	10.398%	1.291%
2014	106,566	920,254	1,026,820	15.791%	10.378%	1.408%
2015	108,032	935,377	1,043,409	16.046%	10.354%	1.376%
2016	109,530	950,862	1,060,392	16.307%	10.329%	1.387%
2017	111,107	967,069	1,078,176	16.581%	10.305%	1.440%
2018	112,683	983,500	1,096,183	16.858%	10.280%	1.418%
2019	114,246	999,809	1,114,055	17.133%	10.255%	1.387%
2020	115,882	1,016,756	1,132,638	17.418%	10.231%	1.432%
2021	117,512	1,033,601	1,151,113	17.702%	10.209%	1.407%
2022	119,321	1,050,965	1,170,286	17.997%	10.196%	1.539%
2023	120,951	1,068,264	1,189,215	18.288%	10.171%	1.366%
2024	122,662	1,085,549	1,208,211	18.581%	10.152%	1.415%
2025	124,394	1,102,927	1,227,321	18.874%	10.135%	1.412%
2026	126,139	1,120,272	1,246,411	19.168%	10.120%	1.403%
2027	127,858	1,138,067	1,265,925	19.468%	10.100%	1.363%
2028	129,573	1,155,676	1,285,249	19.765%	10.082%	1.341%
2029	131,306	1,173,570	1,304,876	20.067%	10.063%	1.337%
2030	133,050	1,191,238	1,324,288	20.366%	10.047%	1.328%

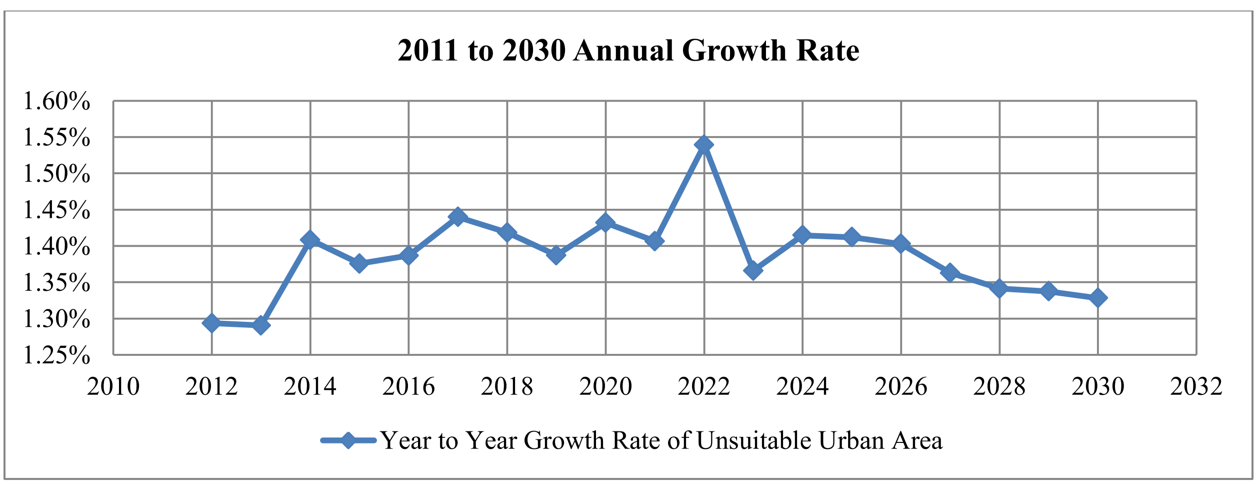


Figure 62. Annual growth rate of environmentally unsuitable urban development, 2011 to 2030, baseline1: environmental suitability vs. scenario 1: development corridors.

Local policies that protect environmental sensitive areas within the development corridors are critical to create an environmentally-responsible urban form of the region. Zooming in to the east shore of Lake Tai area, the partial area images provide more details for comparison between 2011 and 2030. The black cells represented urbanized area and the red cell represented where environmentally unsuitable development occurred. In these images, there are two major urban settlements: Wuxi to the upper left and Suzhou to the lower right. A visual inspection reveals two clusters of red grid cells to the north of Suzhou and northwest of Wuxi. These detailed images provided spatial evidence where unsuitable growth occurred and in which year, so that local policy makers can use this information to prepare reaction time and maneuvering space.

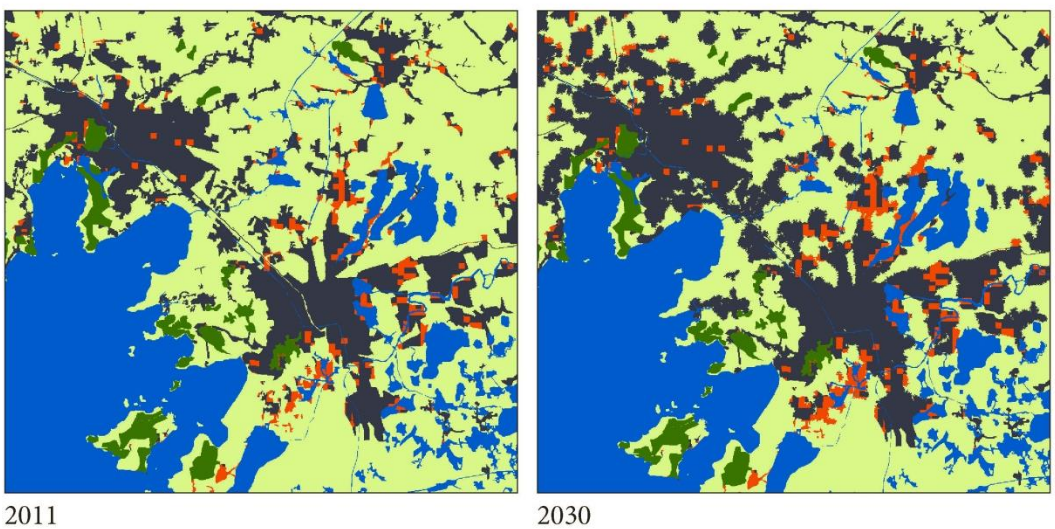


Figure 63. Environmental unsuitable area urban development, partial area comparison between 2011 and 2030, baseline1: environmental suitability vs. scenario 1: development corridors.

Figure 64a shows the changes of urbanized areas predicted by the Scenario Cellular Automata model, 2011 vs. 2030. Figure 64b shows the changes of urbanized areas with existing urban conditions. The interim year changes are summarized in an Appendix.

Figure 64a. the changes of urbanized areas predicted by the Scenario Cellular Automata model, 2011 vs. 2030. Baseline1: environmental suitability vs. scenario 1: development corridors.

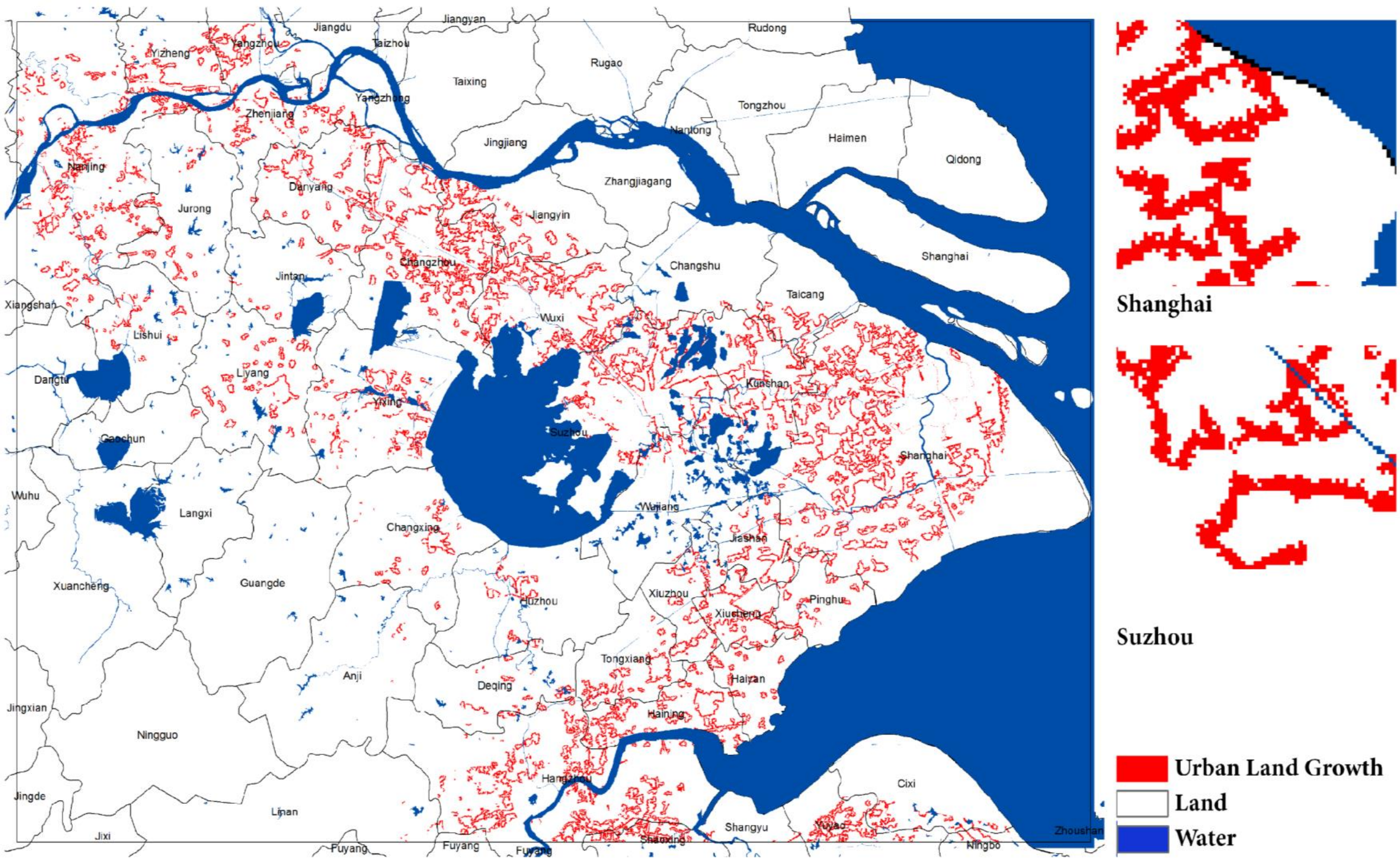
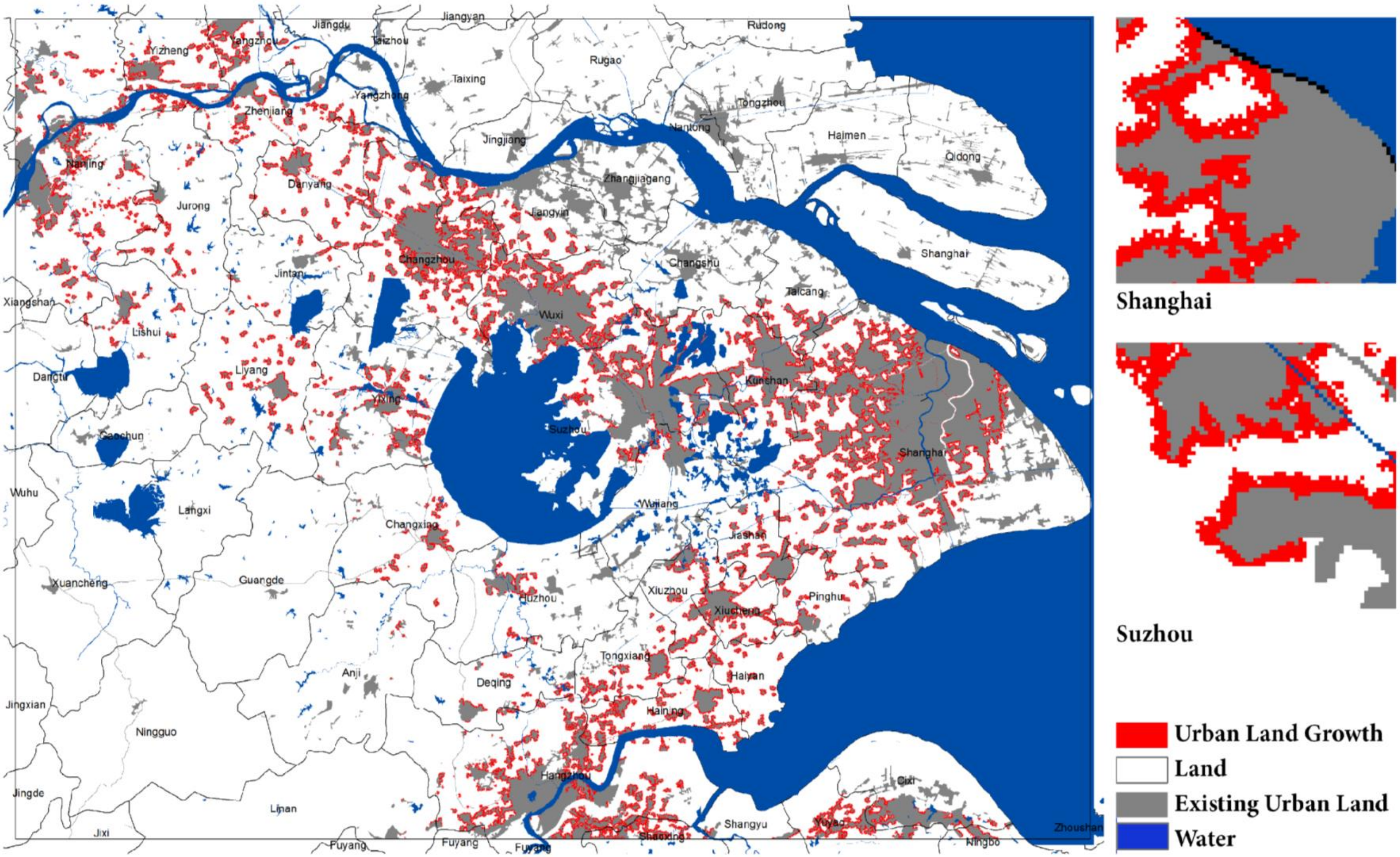


Figure 64b. The changes of urbanized areas with existing urban conditions, 2011 vs. 2030.
Baseline1: environmental suitability vs. scenario 1: development corridors.



ii. Baseline 1: environmental suitability vs. scenario 2: development corridors, plus big city growth.

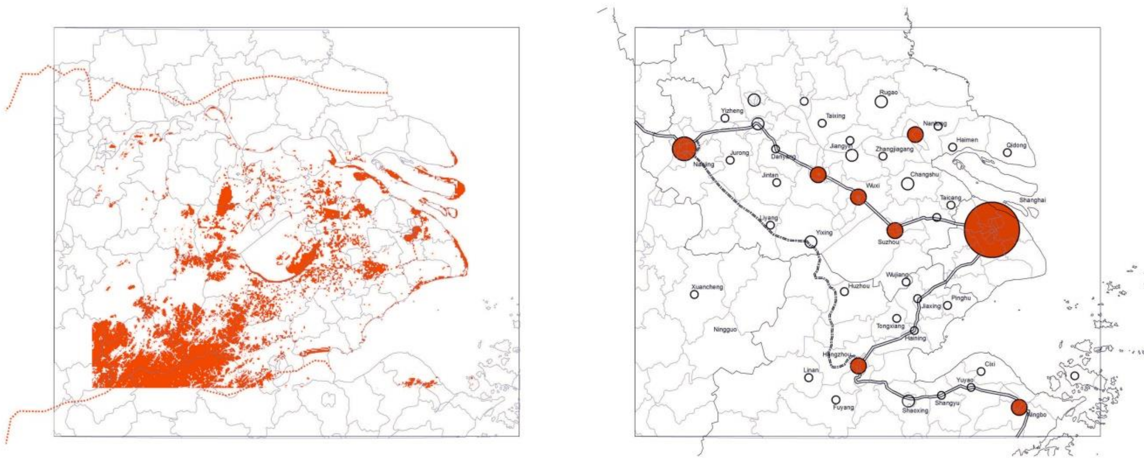


Figure 65. Environmental unsuitable area (left) and development corridors, plus big city growth (right), 2010.

The base maps of environmental suitability and development corridors, plus big city growth are shown in Figure 65. The results from the Scenario Cellular Automata model predictions of annual growth and environmentally unsuitable development maps are shown in Figure 66a. Again, the black cells are the urbanized land, the red cells are where unsuitable growth occurred, the green cells are the protected forest and the blue cells are water. The buffer zone, which was created to avoid significant impact from neighboring large cities, was also represented in Figure 66b for two selected years, 2011 and 2030. The individual maps of interim years are again reproduced in an Appendix.

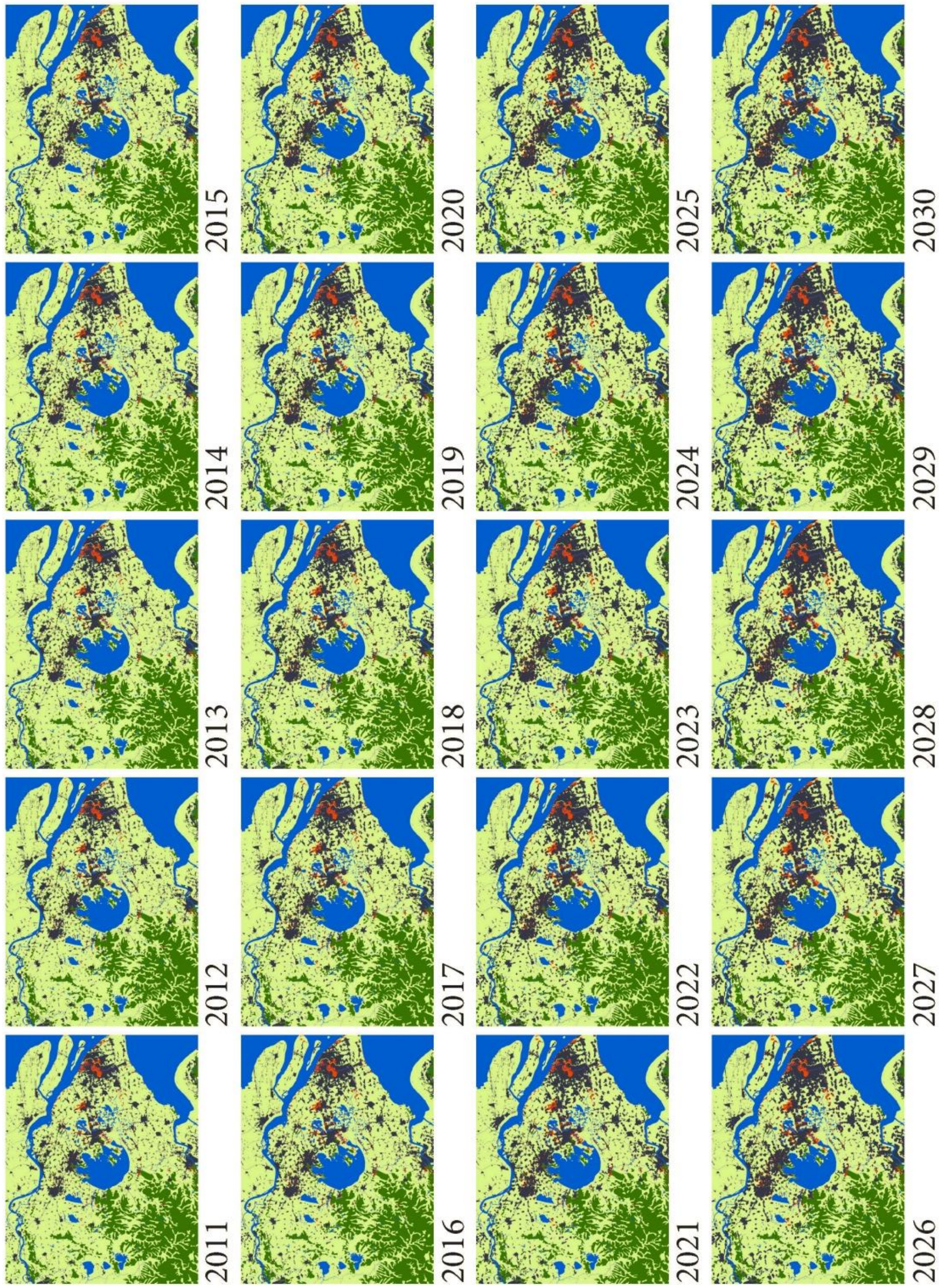
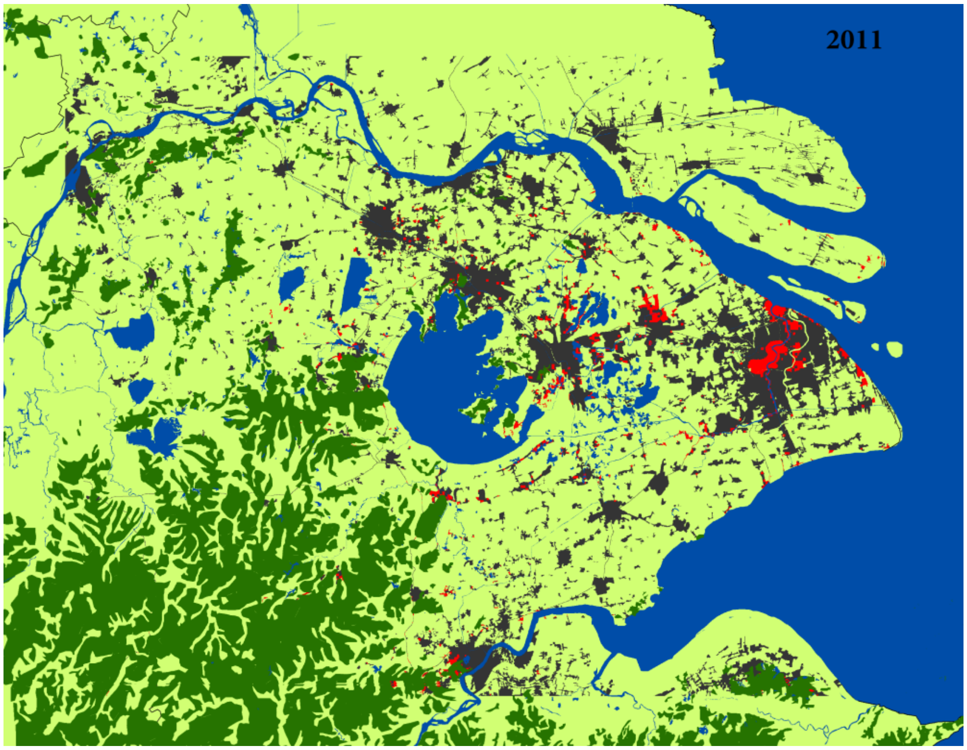


Figure 66a. Annual growth prediction and environmental unsuitable development, 2011-2030, baseline1: environmental suitability vs. scenario 2: development corridors, plus big city growth.



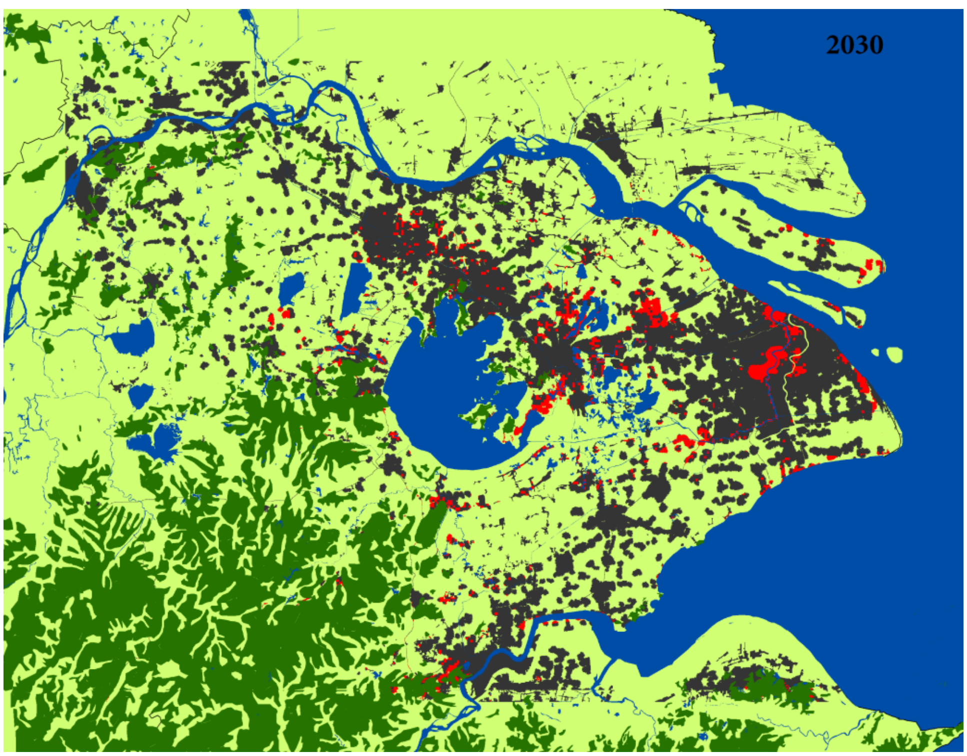


Figure 66b. Scenario Cellular Automata model predicted urban growth map with buffer zone around study area, 2010 (upper) and 2030 (lower), baseline1: environmental suitability vs. scenario 2: development corridors, plus big city growth.

The results were summarized in Table 11. As before, the number of grid cells in urbanized area was first counted by year from 2011 to 2030. Then the number of grid cells in suitable areas was deducted from the urbanized area for each year. The results were the number of cells in unsuitable areas for the model prediction duration, listed in column ‘Number of cells in unsuitable area’. These numbers were then divided by the total number of grid cells of the entire study region, again as before. The results are shown in column ‘Urbanization rate based on land area’.

One of the outcomes is the ‘Percentage of urban development in unsuitable area’, which revealed a decreasing trend of urban development in unsuitable areas. Basically, if urban growth were constrained to the development corridors and to big cities, the rate of urbanization in environmentally sensitive areas would drop, much as before, from 10.42% in 2011 to 10.02% in 2030. By emphasizing urban growth in the development corridors and big cities, again the outcome of urbanization patterns also started to evolve in a more environmentally sensitive direction. The explanation is also much the same as before. First, the rate of growth in environmentally suitable areas was again higher than in unsuitable areas. Second, the current development corridors and big cities were in areas distant from the major environmental protection zones. Third, the big cities provided higher urban intensity and grew in a more efficient or confined urban form that reduced infringement on environmentally sensitive areas. However, from 2011 to 2016, there is a gradual increase in the annual growth rate of unsuitable urban development, although from 2016, the rate slowed down until 2030 (Figure 68). A relatively environmentally sensitive policy, despite the long term positive impact, could still yield some short term advantges. This can be explained by the momentum of current development trends which take some time to readapt to new development policies.

Table 11. Environmental suitability and development corridors, plus big city growth.

Year	Scenario 2: Big Cities Grow Bigger + Development Corridors					
	Number of Cells in Unsuitable Urban Area	Number of Cells in Suitable Urban Area	Number of Cells in Urbanized Area	Urbanization Rate based on Land Area	Percentage of Growth in Unsuitable Urban Area	Year to Year Growth Rate of Unsuitable Urban Area
2011	103,918	893,629	997,547	15.341%	10.417%	-
2012	106,986	924,154	1,031,140	15.857%	10.376%	2.952%
2013	110,260	956,655	1,066,915	16.408%	10.334%	3.060%
2014	113,677	990,337	1,104,014	16.978%	10.297%	3.099%
2015	117,190	1,024,512	1,141,702	17.558%	10.264%	3.090%
2016	120,892	1,059,288	1,180,180	18.149%	10.244%	3.159%
2017	124,577	1,093,890	1,218,467	18.738%	10.224%	3.048%
2018	128,322	1,128,776	1,257,098	19.332%	10.208%	3.006%
2019	131,863	1,163,494	1,295,357	19.921%	10.180%	2.759%
2020	135,487	1,197,872	1,333,359	20.505%	10.161%	2.748%
2021	139,129	1,232,131	1,371,260	21.088%	10.146%	2.688%
2022	142,731	1,266,193	1,408,924	21.667%	10.130%	2.589%
2023	146,217	1,299,981	1,446,198	22.240%	10.110%	2.442%
2024	149,748	1,333,346	1,483,094	22.808%	10.097%	2.415%
2025	153,243	1,366,830	1,520,073	23.377%	10.081%	2.334%
2026	156,705	1,399,747	1,556,452	23.936%	10.068%	2.259%
2027	160,071	1,432,513	1,592,584	24.492%	10.051%	2.148%
2028	163,454	1,465,086	1,628,540	25.045%	10.037%	2.113%
2029	166,848	1,497,176	1,664,024	25.590%	10.027%	2.076%
2030	170,184	1,528,877	1,699,061	26.129%	10.016%	1.999%

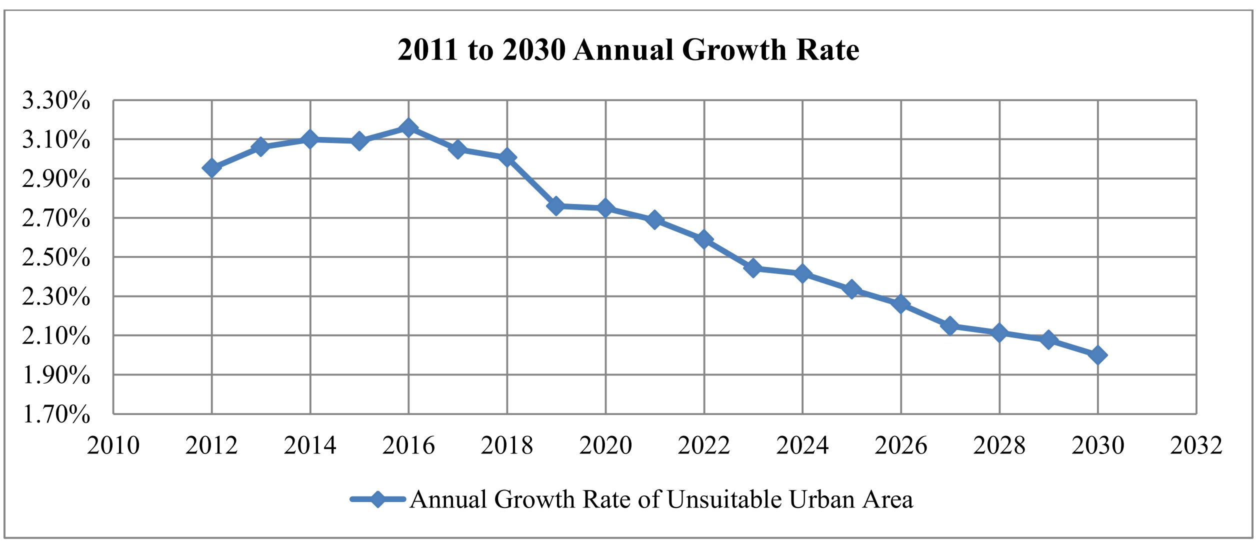
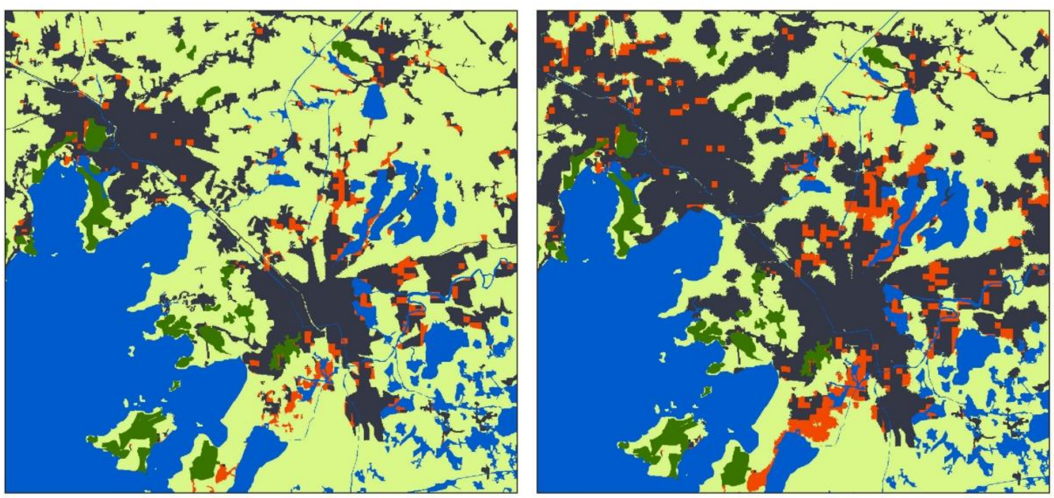


Figure 67. Annual growth rate of unsuitable urban development, 2011 to 2030, baseline1: environmental suitability vs. scenario 2: development corridors, plus big city growth.

Local policies which protect environmentally sensitive areas within the development corridors and big cities areas are critical to create an environmentally responsible urban form in the region. The same area, the east shore of Lake Tai area, was used to provide further detailed comparison between 2011 and 2030. Again, the black cells represent urbanized areas and the red cells represent where environmentally unsuitable development occurred. Also again in these images, there are two major urban settlements: Wuxi to the upper left and Suzhou to the lower right. A visual inspection revealed two clusters of red grid cells appearing both to the north and south of Suzhou. Around Wuxi, there was some sporadic growth of red cells as well. These detailed outcomes also provide spatial evidence as to where unsuitable growth occurred in which year as before.



2011 2030

Figure 68. Environmental unsuitable area urban development, partial area comparison between 2011 and 2030, baseline1: environmental suitability vs. scenario 2: development corridors, plus big city growth.

Figure 69a shows the changes of urbanized areas predicted by the Scenario Cellular Automata model, 2011 vs. 2030. Figure 69b shows the changes of urbanized areas with existing urban conditions. Again, the individual interim changes are attached in an Appendix.

Figure 69a. The changes of urbanized areas predicted by the Scenario Cellular Automata model, 2011 vs. 2030. Baseline1: environmental suitability vs. scenario 2: development corridors, plus big city growth.

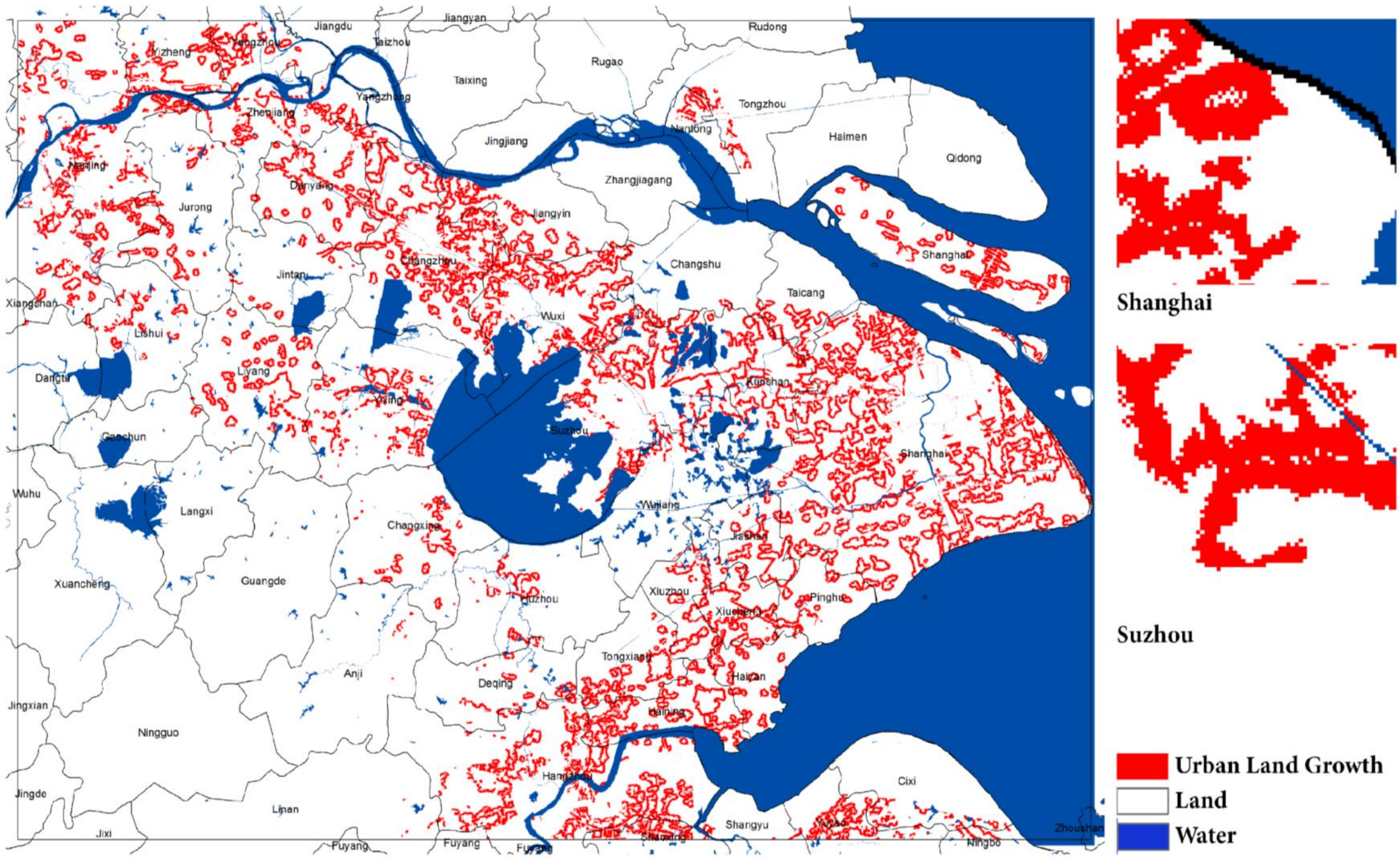
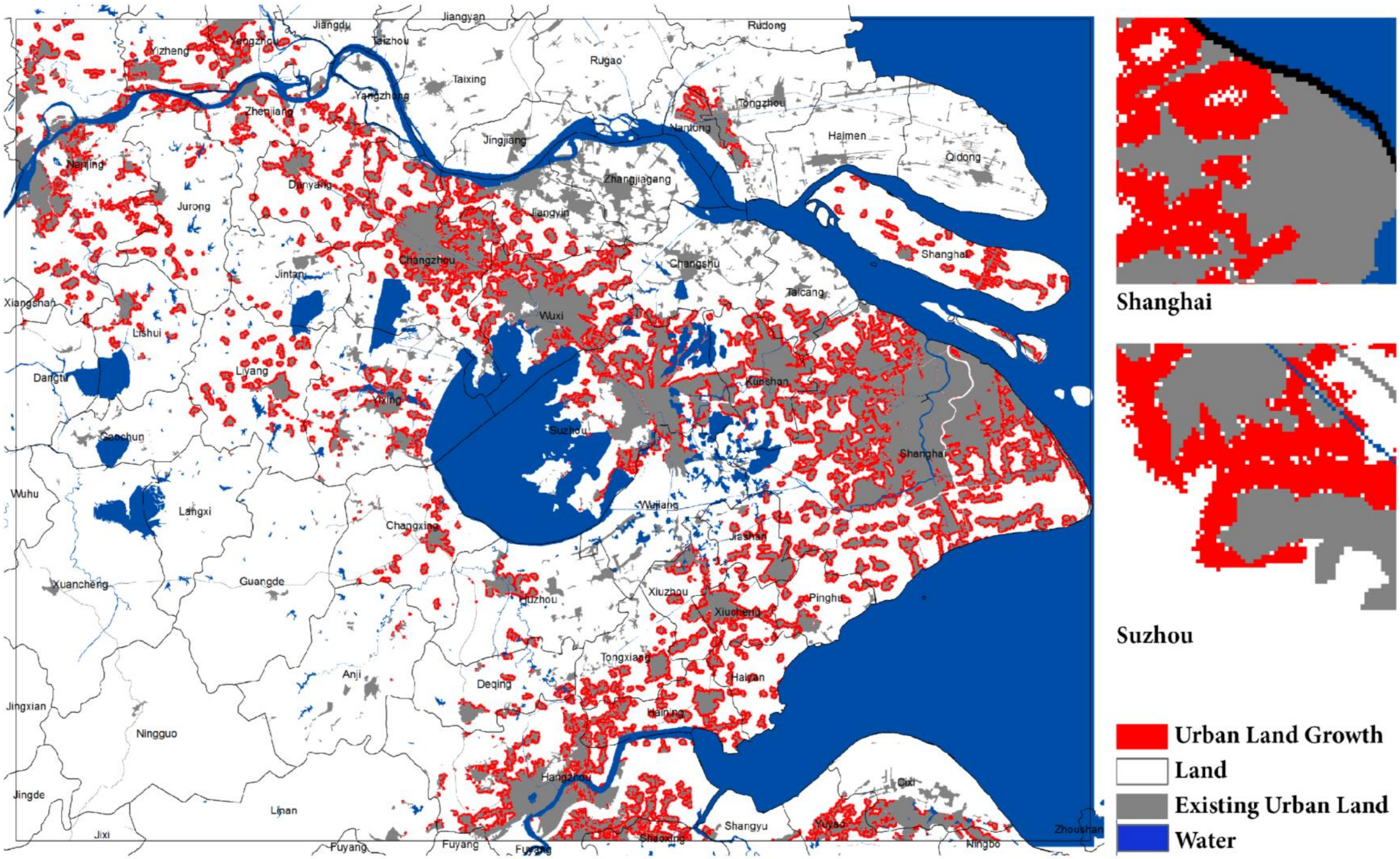


Figure 69b. The changes of urbanized areas with existing urban conditions, 2011 vs. 2030.
Baseline1: environmental suitability vs. scenario 2: development corridors, plus big city growth.



iii. Baseline 1: environmental suitability vs. scenario 3: ecological system concerns, plus development corridors.

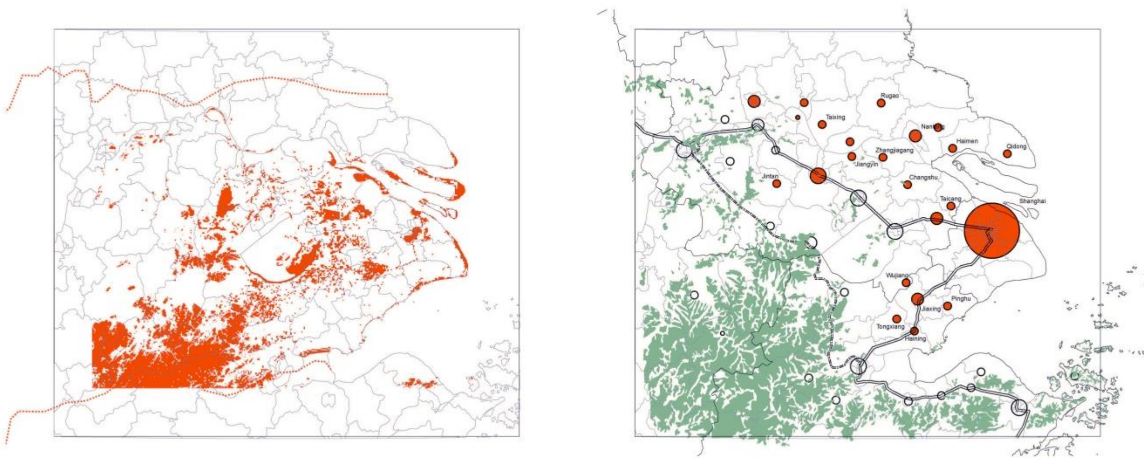


Figure 70. Environmental unsuitable area (left) and ecological system concerns, plus development corridors (right), 2010.

The base maps of environmental suitability and ecological system concerns, plus development corridors are shown in Figure 70. The results from the Scenario Celluar Automata model predictions of annual growth and environmentally unsuitable development maps are depicted in Figure 71a. As before, the black cells are the urbanized land, the red cells are where unsuitable growth occurred, the green cells are the protected forest areas, and the blue cells are water. The buffer zone, which was created to avoid significant impact from neighboring large cities, was also represented in Figure 71b for two selected years, 2011 and 2030. The individual maps of interim years are reproduced in an Appendix.

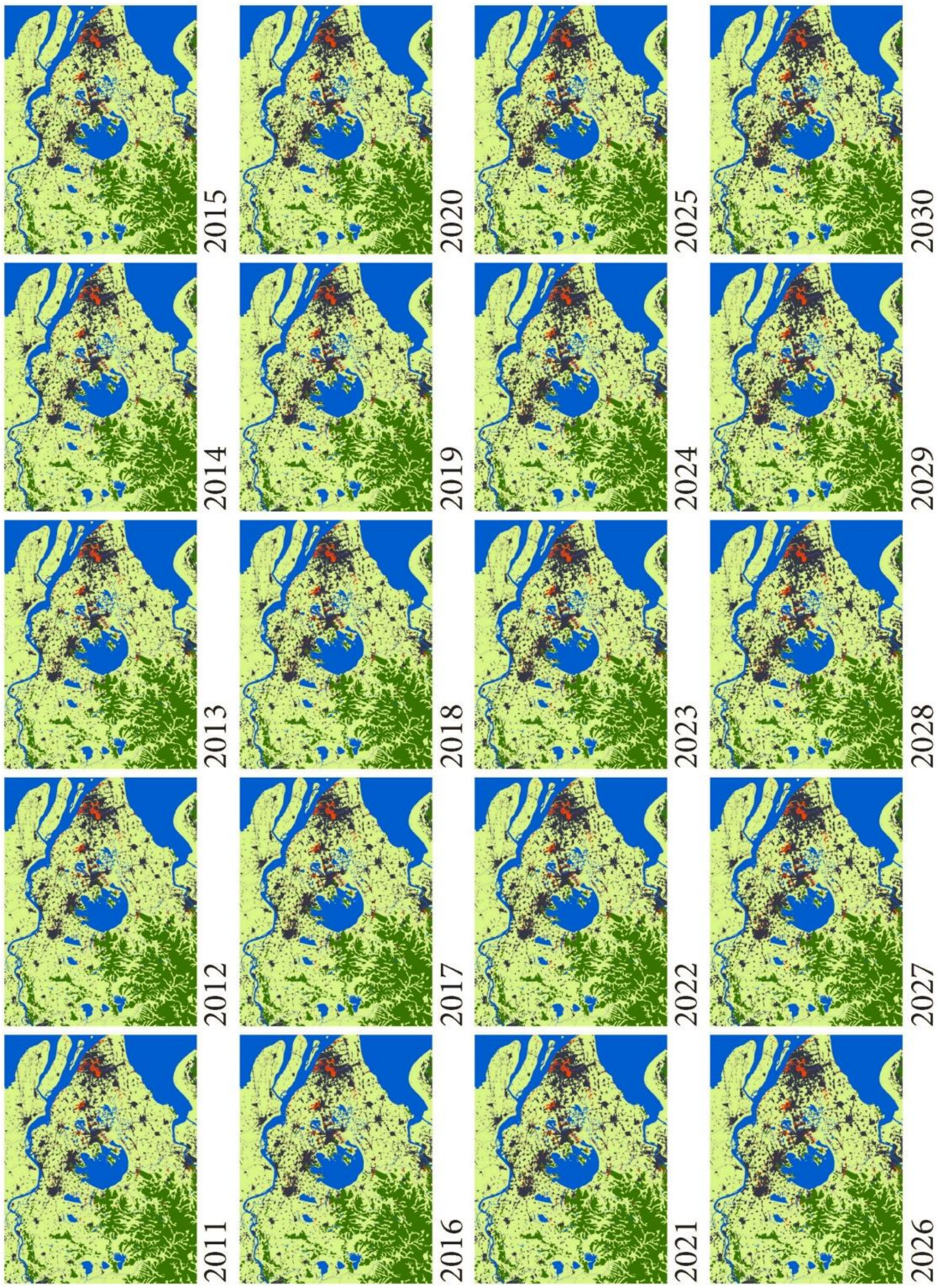


Figure 71a. Annual growth prediction and environmental unsuitable development, 2011-2030, baseline1: environmental suitability vs. scenario 3: ecological system concerns, plus development corridors.

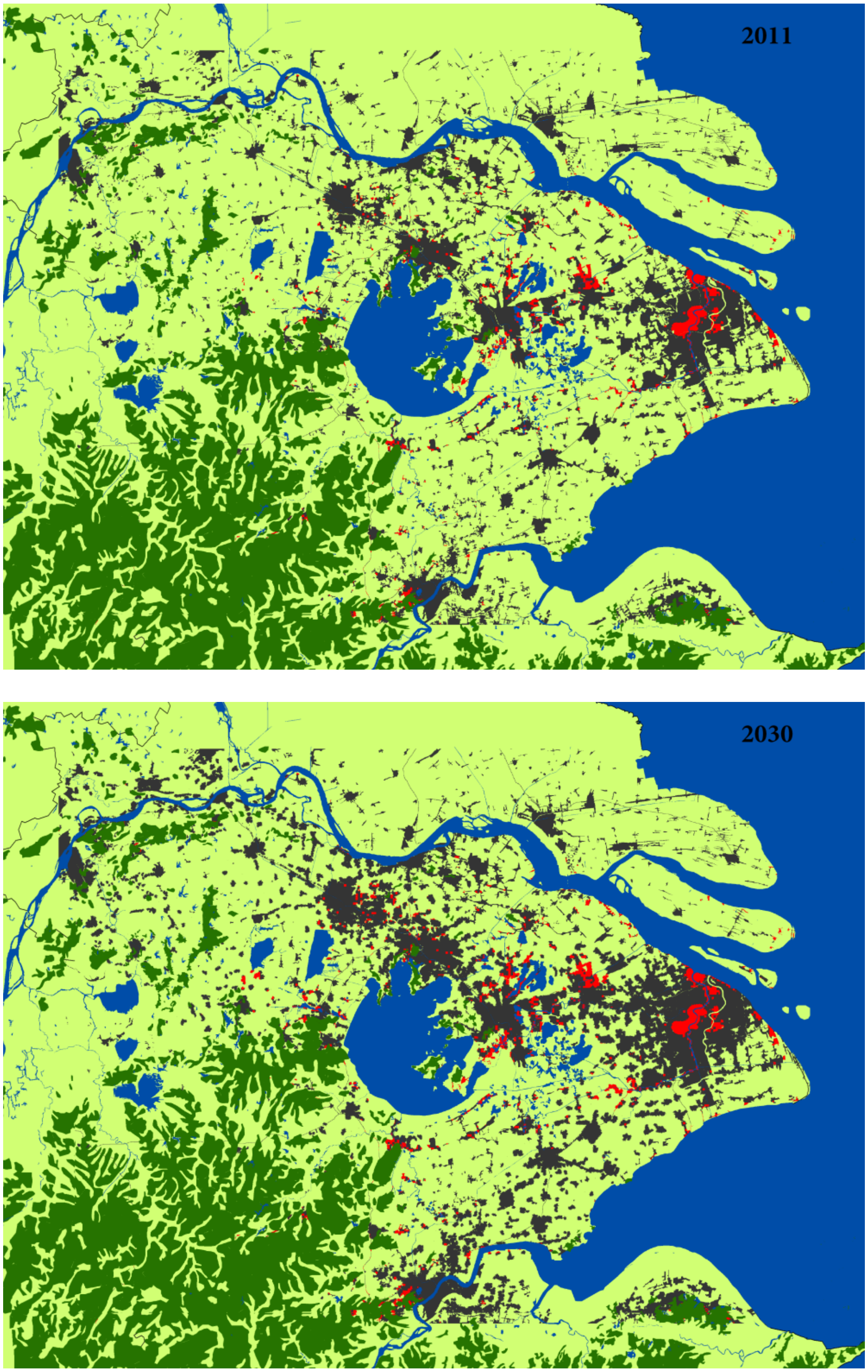


Figure 71b. Scenario Cellular Automata model predicted urban growth map with buffer zone around study area, 2010 (upper) and 2030 (lower), baseline 1: environmental suitability vs. scenario 3: ecological system concerns, plus development corridors.

The results are summarized in Table 12. As before, the number of grid cells in urbanized areas was first counted by year from 2011 to 2030. Then the number of grid cells in suitable area was deducted from the urbanized area for each year. The results were the number of cells in unsuitable areas for the model prediction duration, listed in column 'Number of cells in unsuitable area'. Again, these numbers were then divided by the total number of grid cells of the entire study region. The result was shown in column 'Urbanization rate based on land area'.

One of the outcomes is the 'Percentage of urban development in unsuitable areas', which, overall, revealed a downward trend of urban development in unsuitable areas. Basically, if urban growth was directed by emphasizing ecological system concerns and controlled to the development corridors, the rate of urbanization in environmental sensitive areas will drop from 10.45% in 2011 to 10.06% in 2030, a little less than the previous two prospectives. The other outcome is the 'Year to year growth rate of unsuitable urban area', which revealed an upward trend followed by a downward trend, with a few peaks, notably in 2015, 2020, and 2024 (Figure 72). The shape of the curve mimics the elevation of a rolling hill, with a few cycles of ups and downs. The reason why this happened is due to the impact of environmental factors. First, the momentum of current development patterns carries the urban growth to some unsuitable area. This is when the growth rate of urbanization in unsuitable areas rose up, i.e., the peak of the curve. Then, the urban growth, or expansion, encountered environmental sensitive areas which were designated as 'prohibited area for urban growth', meaning no land use conversion from farm land to urban land is allowed. This is when the growth rate of urbanization in unsuitable area slowed down, i.e. the valley of the curve. The explanations are more complicated than the previous scenarios and need further investigation at a city-level.

Table 12. Environmental suitability and ecological system concerns, plus development corridors.

	Scenario 3: Ecological System Concerns (Forest Protection) + Development Corridors					
Year	Number of Cells in Unsuitable Urban Area	Number of Cells in Suitable Urban Area	Number of Cells in Urbanized Area	Urbanization Rate based on Land Area	Percentage of Growth in Unsuitable Urban Area	Year to Year Growth Rate of Unsuitable Urban Area
2011	102,443	877,966	980,409	15.077%	10.449%	-
2012	103,707	891,475	995,182	15.304%	10.421%	1.234%
2013	105,061	905,500	1,010,561	15.541%	10.396%	1.306%
2014	106,504	920,093	1,026,597	15.788%	10.374%	1.373%
2015	107,984	935,143	1,043,127	16.042%	10.352%	1.390%
2016	109,458	950,395	1,059,853	16.299%	10.328%	1.365%
2017	111,000	966,514	1,077,514	16.571%	10.301%	1.409%
2018	112,605	982,614	1,095,219	16.843%	10.282%	1.446%
2019	114,238	998,717	1,112,955	17.116%	10.264%	1.450%
2020	115,939	1,015,381	1,131,320	17.398%	10.248%	1.489%
2021	117,572	1,032,037	1,149,609	17.679%	10.227%	1.408%
2022	119,194	1,048,898	1,168,092	17.964%	10.204%	1.380%
2023	120,885	1,066,060	1,186,945	18.253%	10.185%	1.419%
2024	122,624	1,083,096	1,205,720	18.542%	10.170%	1.439%
2025	124,334	1,100,428	1,224,762	18.835%	10.152%	1.395%
2026	125,967	1,117,555	1,243,522	19.124%	10.130%	1.313%
2027	127,656	1,134,873	1,262,529	19.416%	10.111%	1.341%
2028	129,367	1,151,959	1,281,326	19.705%	10.096%	1.340%
2029	131,081	1,169,103	1,300,184	19.995%	10.082%	1.325%
2030	132,750	1,186,295	1,319,045	20.285%	10.064%	1.273%

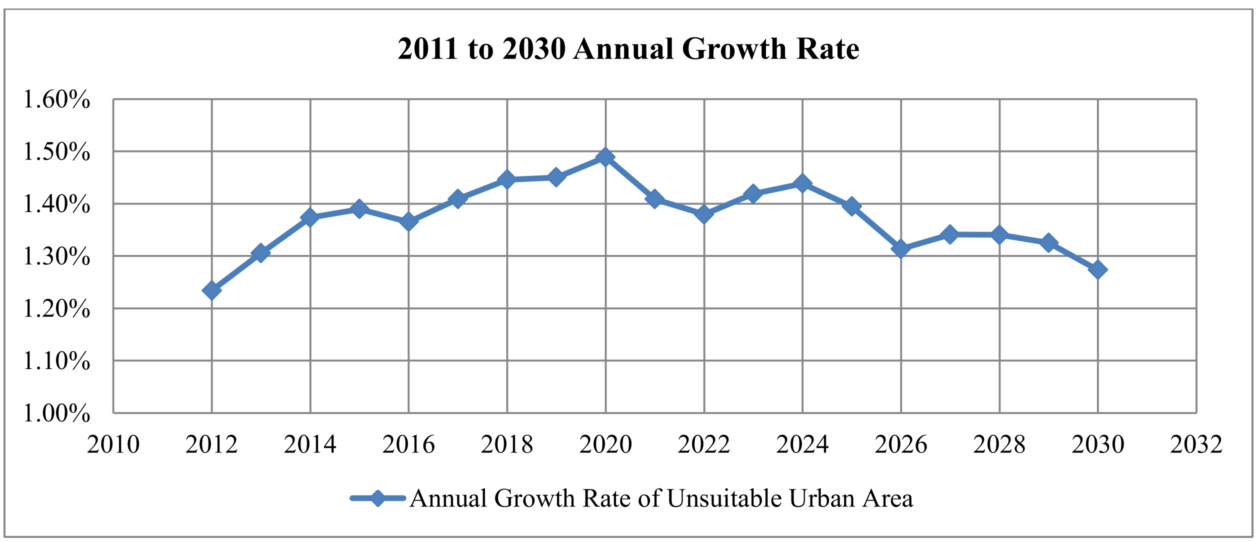


Figure 72. Annual growth rate of unsuitable urban development, 2011 to 2030, baseline 1: environmental suitability vs. scenario 3: ecological system concerns, plus development corridors.

What can be concluded from this scenario is that the specific goal-oriented policy, such as ecological system concerns which was tailored to forest protection, is the most effective policy to address environmental suitability.

Local policies which protect environmental sensitive areas with ecological system concerns and focus on the development corridors are critical to create an environmentally responsible urban form of the region. The east shore of Lake Tai area was used to provide further detailed comparison between 2011 and 2030. As before, the black cells represented urbanized area and the red cells represented where environmentally unsuitable development occurred. Again, in these images, there are two major urban settlements: Wuxi to the upper left and Suzhou to the lower right. A visual inspection revealed no significant clusters of red grid cells around Wuxi and Suzhou. As before, these detailed outcome images provided spatial evidences where the unsuitable growth occurred in each year, so that local policy makers can use this information to prepare appropriate spatio-temporal reactions..

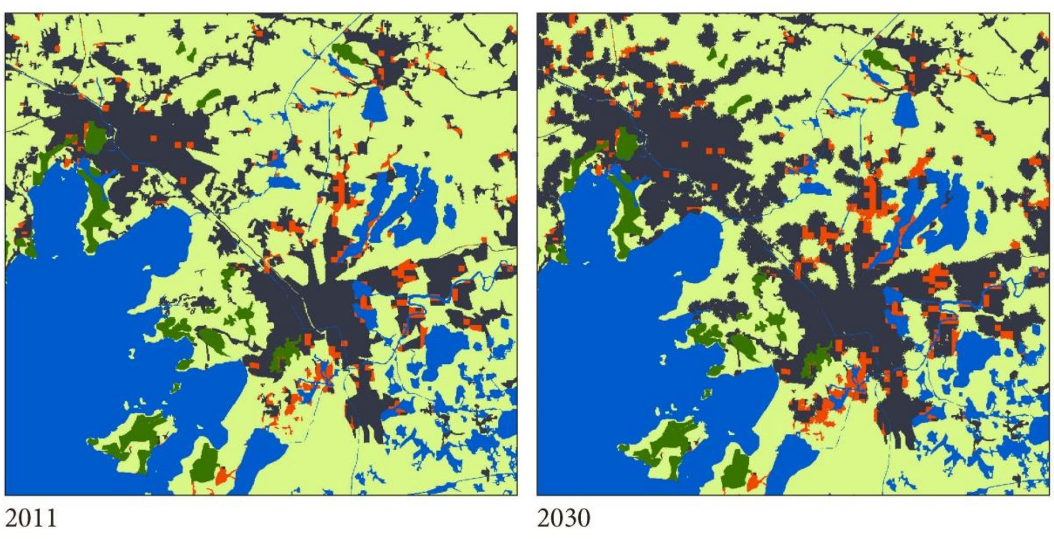


Figure 73. Environmental unsuitable area urban development, partial area comparison between 2011 and 2030, baseline 1: environmental suitability vs. scenario 3: ecological system concerns, plus development corridors.

Figure 74a. The changes of urbanized areas predicted by the Scenario Cellular Automata model, 2011 vs. 2030. Baseline 1: environmental suitability vs. scenario 3: ecological system concerns, plus development corridors.

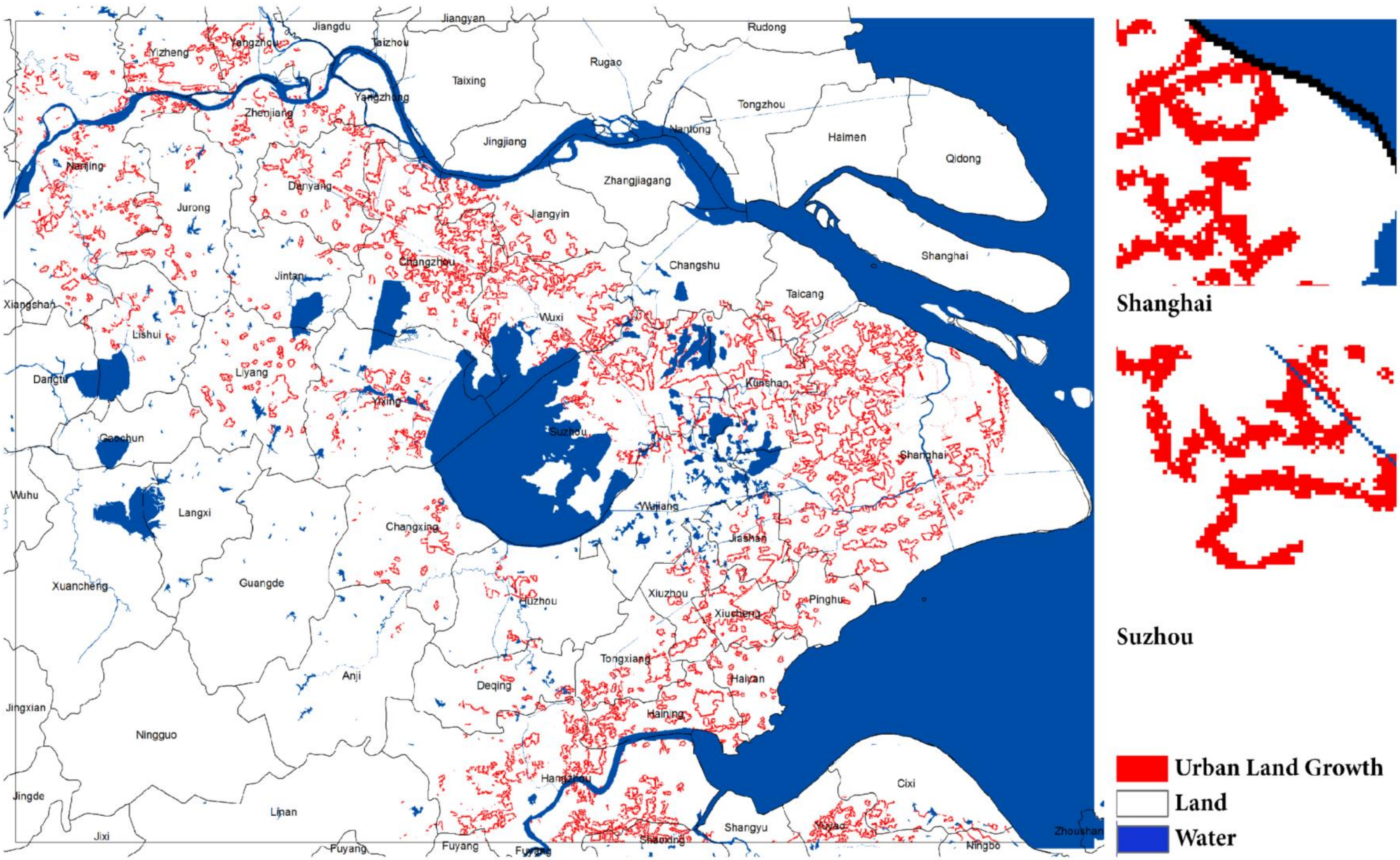
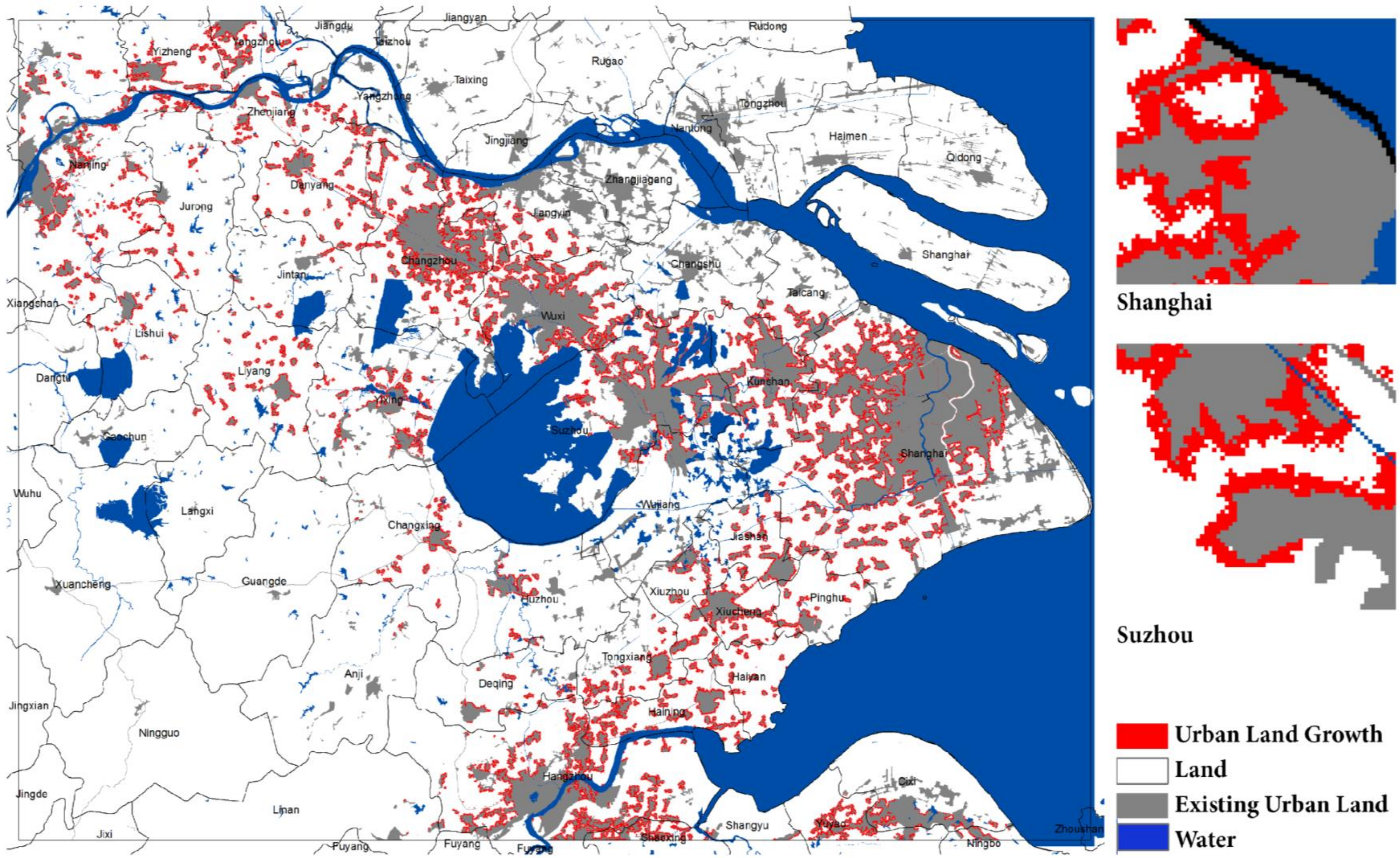


Figure 74b. The changes of urbanized areas with existing urban conditions, 2011 vs. 2030. Baseline 1: environmental suitability vs. scenario 3: ecological system concerns, plus development corridors.



iv. Baseline 1: environmental suitability vs. scenario 4: disaster prevention, plus development corridors.

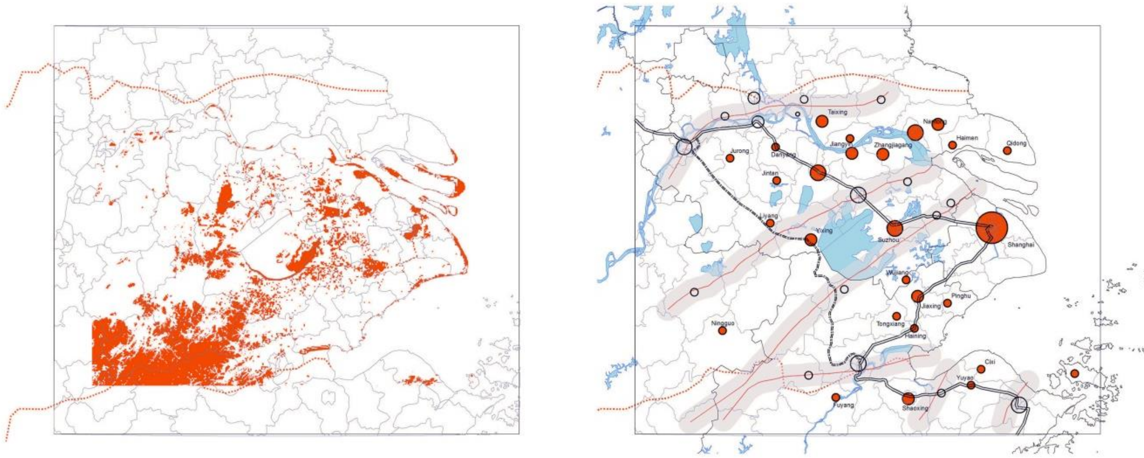


Figure 75. Environmental unsuitable area (left) and disaster prevention, plus development corridors (right), 2010.

The base maps of environmental suitability and disaster prevention, plus development corridors are shown in Figure 75, again with results from the Scenario Cellular Automata model predictions of annual growth and environmentally unsuitable development shown in Figure 76a. Again, the black cells are the urbanized land, the red cells are where unsuitable growth occurred, the green cells are the protected forest areas, and the blue cells are water. Also, the buffer zone, which was created to avoid significant impact from neighboring large cities, was also represented in Figure 76b for two selected years, 2011 and 2030. As before, the individual maps for interim years are reproduced in an Appendix.

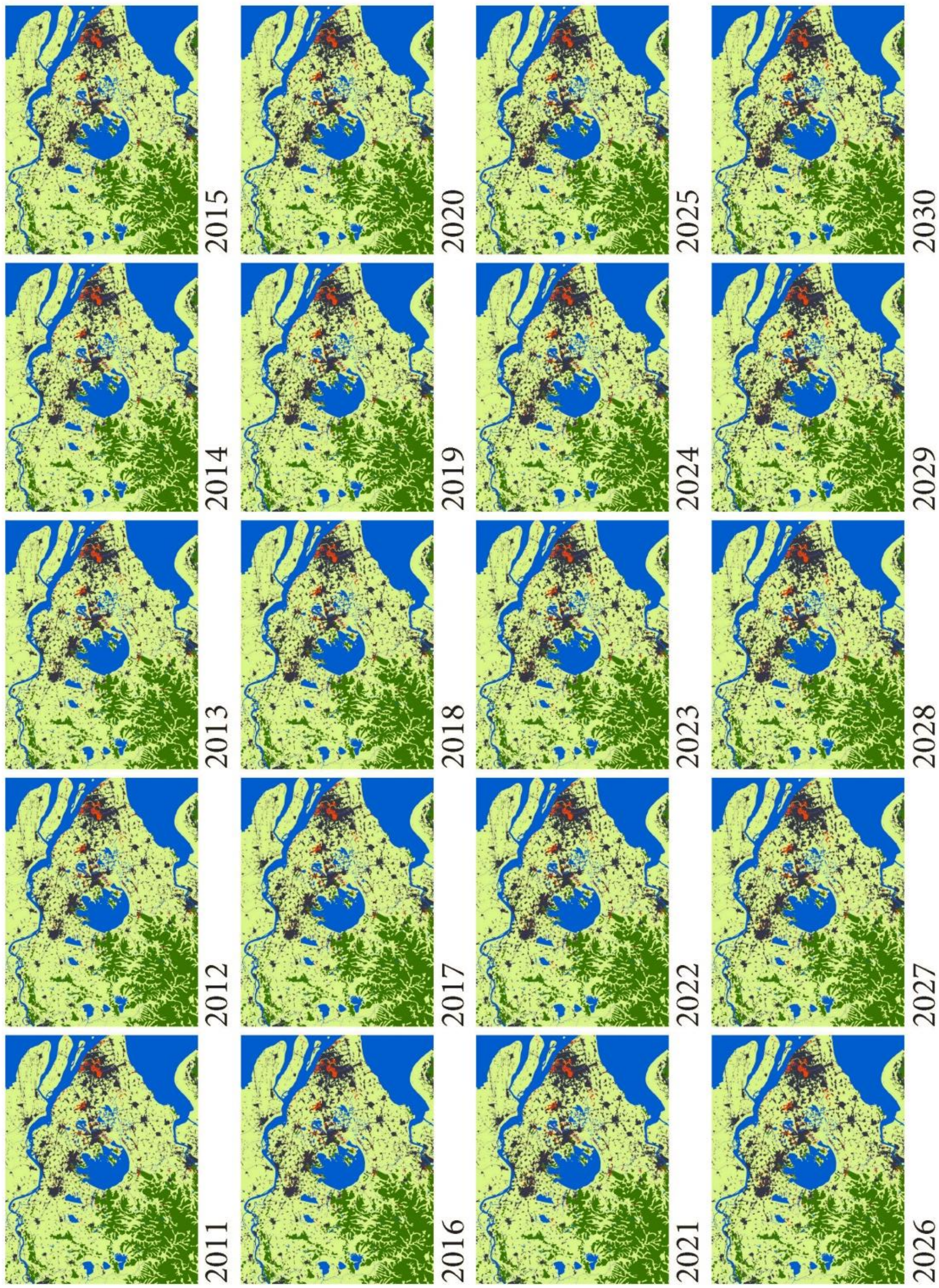
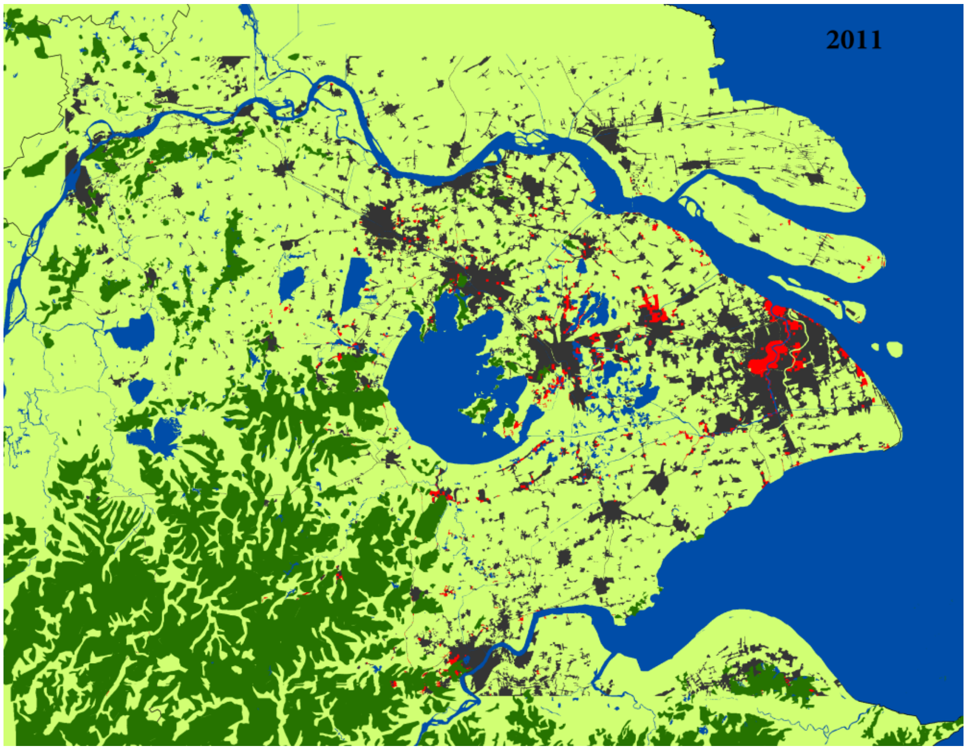


Figure 76a. Annual growth prediction and environmental unsuitable development, 2011-2030, baseline1: environmental suitability vs. scenario 4: disaster prevention, plus development corridors.



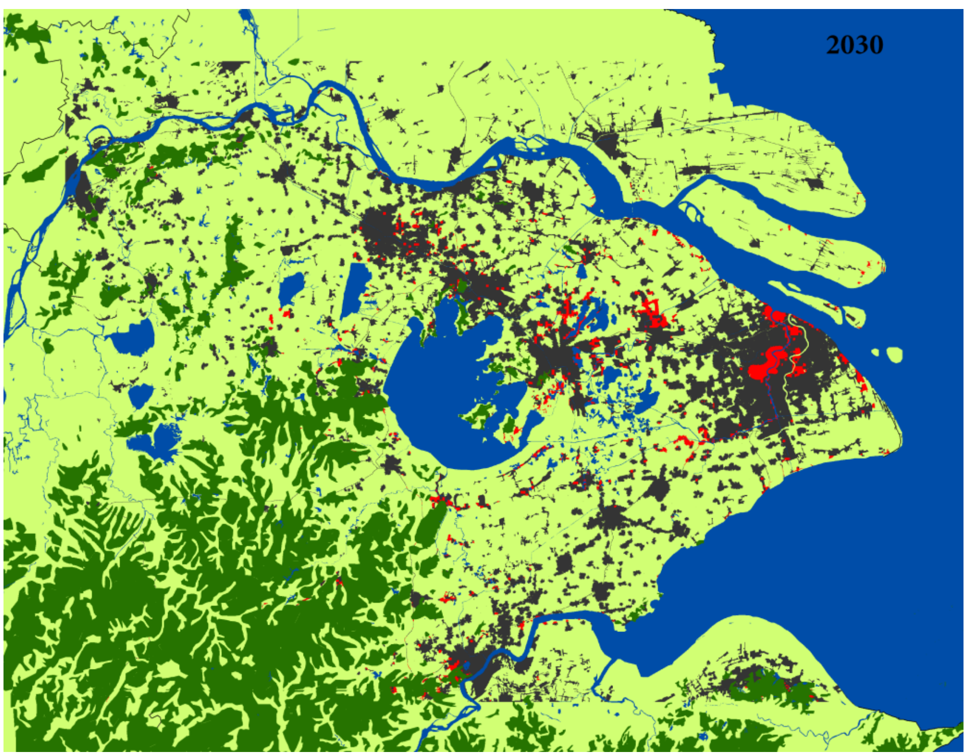


Figure 76b. Scenario Cellular Automata model predicted urban growth map with buffer zone around study area, 2010 (upper) and 2030 (lower), baseline1: environmental suitability vs. scenario 4: disaster prevention, plus development corridors.

The results are summarized in Table 12. The number of grid cells in urbanized area was first counted by year from 2011 to 2030 as before, then the number of grid cells in suitable areas was deducted from the urbanized area for each year. Like other projections, the results were the number of cells in unsuitable areas for the model prediction duration, listed in column 'Number of cells in unsuitable area'. These numbers were then divided by the total number of grid cells of the entire study region and the results shown in column 'Urbanization rate based on land area'.

One of the outcomes is the 'Percentage of urban development in unsuitable area', which revealed a downward trend of urban development in unsuitable areas. Basically, if urban growth were directed by emphasizing disaster prevention and restrained to the development corridors, the rate of urbanization in environmental sensitive area will drop from 10.44% in 2011 to 10.03% in 2030, the highest so far of the projections. Though not directly comparable to the result from the generic model of Cellular Automata using SLEUTH because of the changing growth coefficient number, the descending trend of all four scenarios indicated that certain top-down policy regulations and management guidelines can potentially move urban growth patterns in a more environmentally friendly direction at a regional level.

The other outcome is the 'Year to year growth rate of unsuitable urban area', which revealed an upward trend followed by a downward trend, with a few peaks, notably in 2015, 2019, 2024, and 2028 (Figure 77). The shape of the curve mimics the elevation of a rolling hill, with a few cycles of ups and downs, which also resembles the result from scenario 3. The difference is the sharper angle of the peaks. The explanation here includes that some of the fault lines penetrated the existing urban districts along the development corridors at a near perpendicular angle. This interrupted the continuous growth pattern of urban areas.

Table 13. Environmental suitability and disaster prevention, plus development corridors.

	Scenario 4: Disaster Prevention + Development Corridors					
Year	Number of Cells in Unsuitable Urban Area	Number of Cells in Suitable Urban Area	Number of Cells in Urbanized Area	Urbanization Rate based on Land Area	Percentage of Growth in Unsuitable Urban Area	Year to Year Growth Rate of Unsuitable Urban Area
2011	102,013	874,763	976,776	15.021%	10.444%	-
2012	102,888	884,453	987,341	15.184%	10.421%	0.858%
2013	103,803	894,402	998,205	15.351%	10.399%	0.889%
2014	104,747	904,705	1,009,452	15.524%	10.377%	0.909%
2015	105,711	915,131	1,020,842	15.699%	10.355%	0.920%
2016	106,639	925,934	1,032,573	15.879%	10.328%	0.878%
2017	107,633	937,101	1,044,734	16.066%	10.302%	0.932%
2018	108,638	948,267	1,056,905	16.254%	10.279%	0.934%
2019	109,708	959,423	1,069,131	16.442%	10.261%	0.985%
2020	110,708	970,750	1,081,458	16.631%	10.237%	0.912%
2021	111,725	982,088	1,093,813	16.821%	10.214%	0.919%
2022	112,700	993,477	1,106,177	17.011%	10.188%	0.873%
2023	113,715	1,004,791	1,118,506	17.201%	10.167%	0.901%
2024	114,772	1,016,092	1,130,864	17.391%	10.149%	0.930%
2025	115,795	1,027,303	1,143,098	17.579%	10.130%	0.891%
2026	116,768	1,038,677	1,155,445	17.769%	10.106%	0.840%
2027	117,784	1,050,001	1,167,785	17.959%	10.086%	0.870%
2028	118,832	1,061,294	1,180,126	18.149%	10.069%	0.890%
2029	119,814	1,072,499	1,192,313	18.336%	10.049%	0.826%
2030	120,838	1,083,467	1,204,305	18.520%	10.034%	0.855%

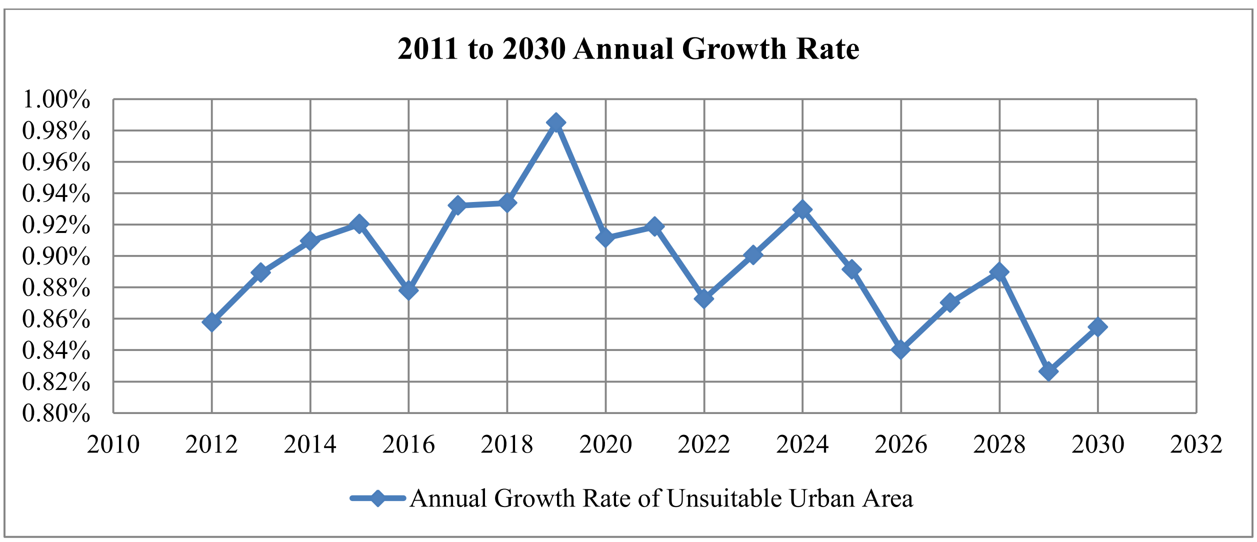


Figure 77. Annual growth rate of unsuitable urban development, 2011 to 2030, baseline1: environmental suitability vs. scenario 4: disaster prevention, plus development corridors.

More detailed observation also reveals more intrinsic characteristics of this scenario. Local policies which protect environmentally sensitive areas with disaster prevention concerns and focus on the development corridors are critical to create an environmentally responsible urban form for the region. The east shore of Lake Tai area was used to provide further detailed comparison between 2011 and 2030. The black cells represented urbanized areas and the red cells represented where environmentally unsuitable development occurred as before. Again, in these images, there are two major urban settlements: Wuxi to the upper left and Suzhou to the lower right.

A visual inspection reveals no significant clusters of red grid cells around Wuxi and Suzhou. These detailed outcomes provide spatial evidences as to where the unsuitable growth occurred and in which year.

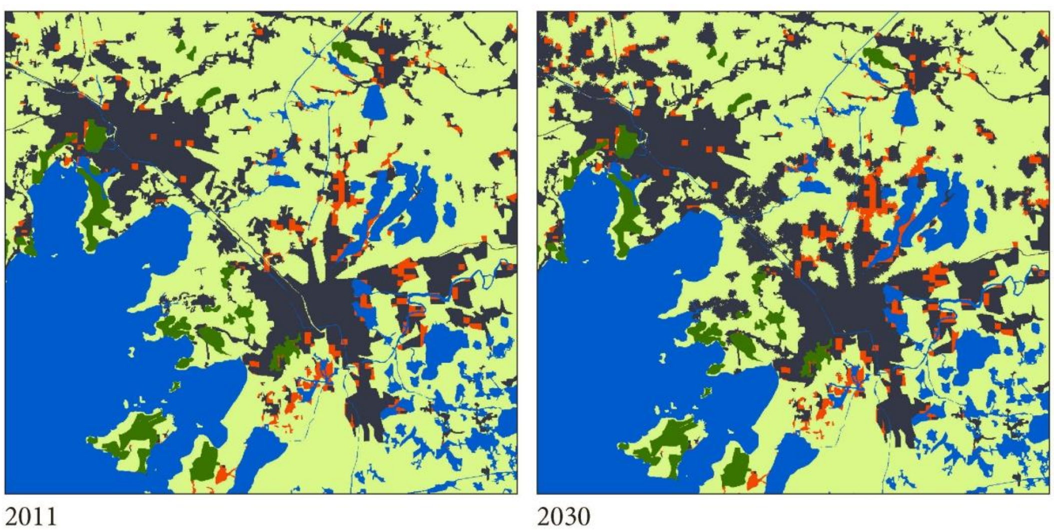


Figure 78. Environmental unsuitable area urban development, partial area comparison between 2011 and 2030, baseline1: environmental suitability vs. scenario 4: disaster prevention, plus development corridors.

Figure 79a shows the changes of urbanized areas predicted by the Scenario Cellular Automata model, 2011 vs. 2030. Figure 79b shows the changes of urbanized areas with existing urban conditions.

Figure 79a. The changes of urbanized areas predicted by the Scenario Cellular Automata model, 2011 vs. 2030. Baseline1: environmental suitability vs. scenario 4: disaster prevention, plus development corridors.

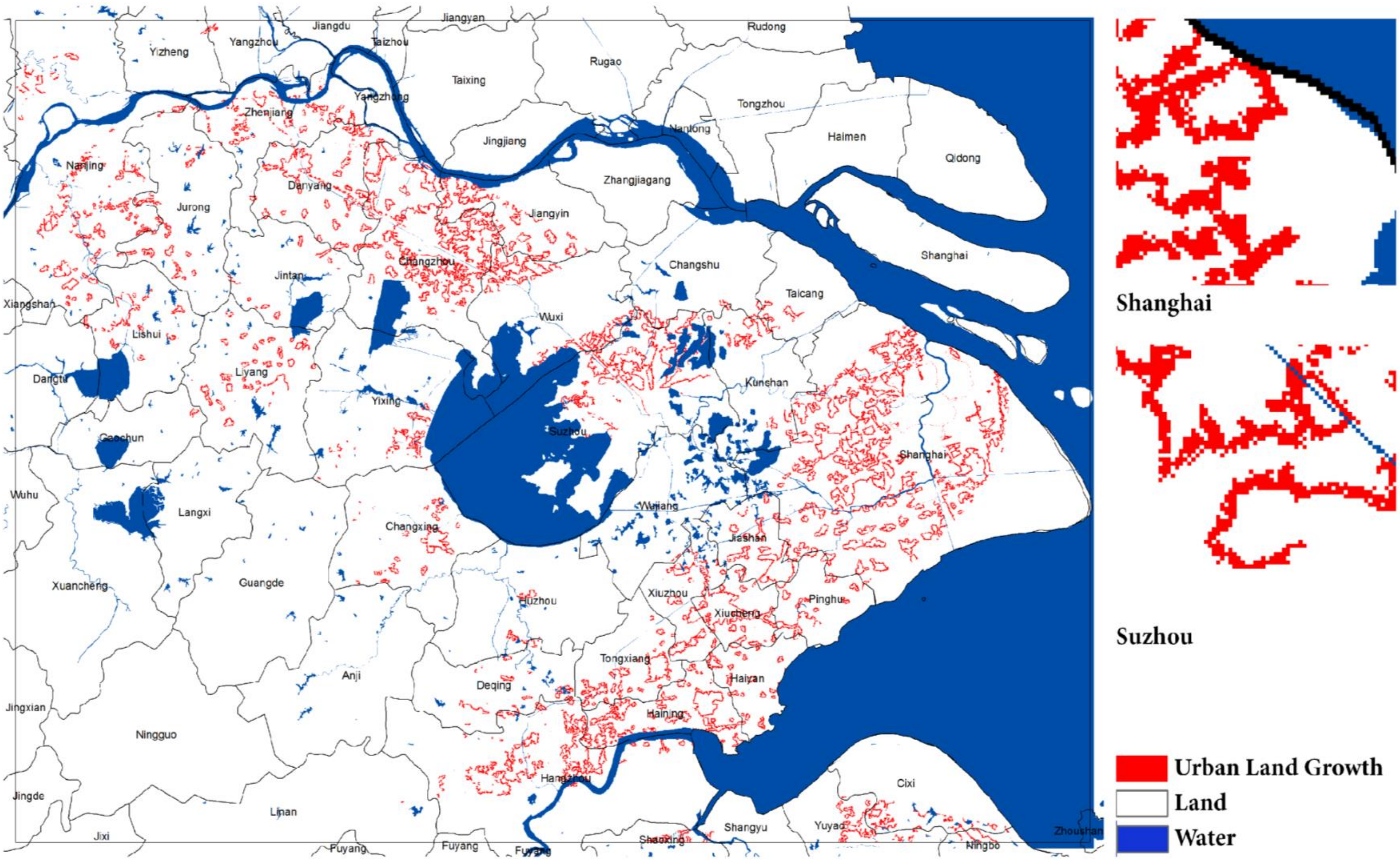
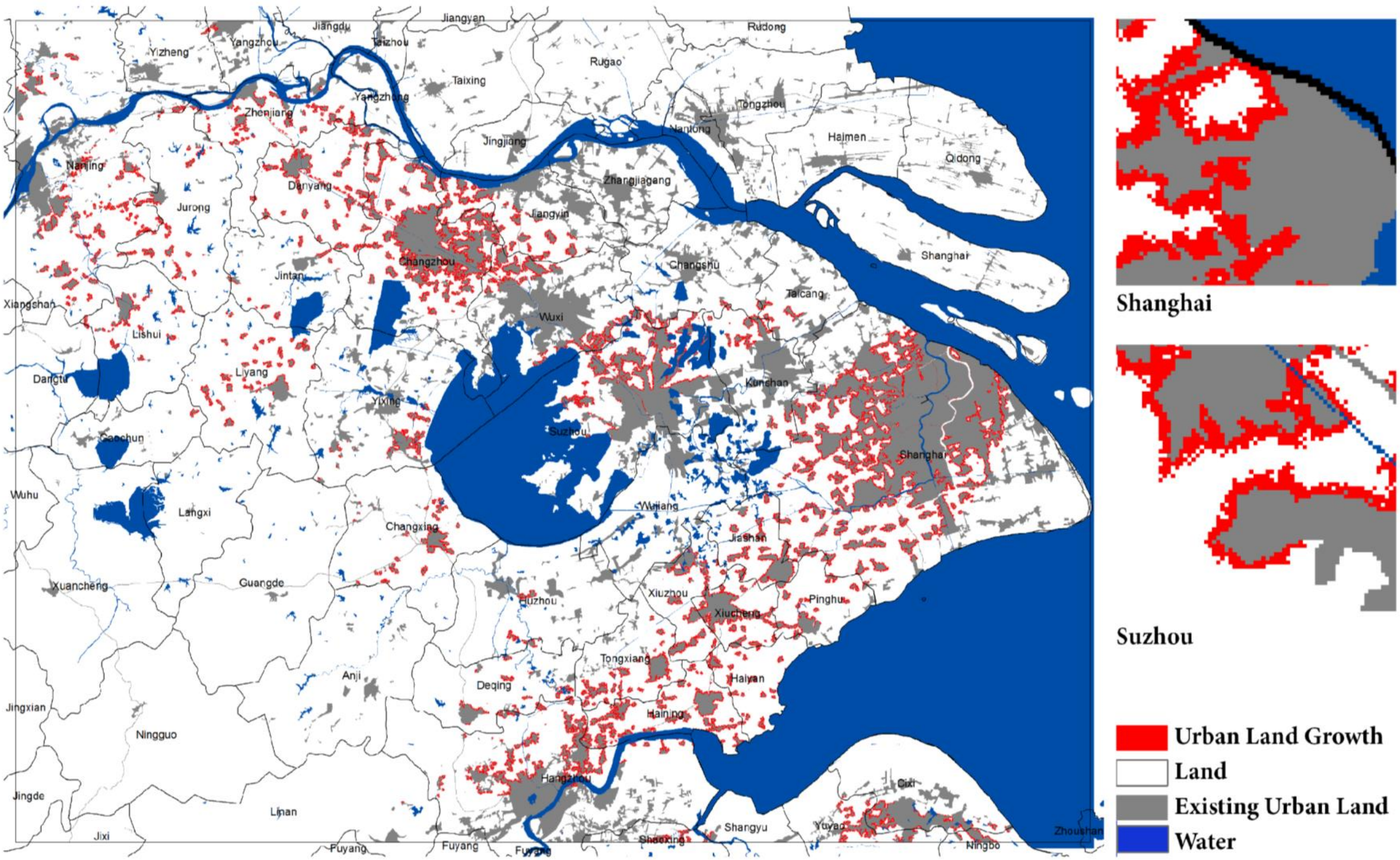


Figure 79b. The changes of urbanized areas with existing urban conditions, 2011 vs. 2030.
Baseline1: environmental suitability vs. scenario 4: disaster prevention, plus development corridors.



b. Baseline 2: economic performance and projections from the four selected scenarios

Economic Performance Index

To measure the Economic Performance Index, the Weighted Linear Combination method was applied. In this research, data normalization was used to prepare the variable input for the Weighted Linear Combination calculation. Here normalization used natural logarithmic values to eliminate outliers and then the logarithmic numbers were scaled between zero and one.

The distribution of normalized Gross Domestic Product was plotted with a scatter chart (Figure 80). The distribution of cities followed the trend line closely with Shanghai staying on top, as tier one, with some distance from the runner-up. With a few exceptions of cities falling behind, as tier three, most of the cities were in the middle tier. This resembled the rank-size distribution of city size following Zipf's law of a stretched exponential distribution. While size, in terms of population, was one of the most important characteristics of a city, there are other dimensions that also contribute to the definition and Gross Domestic Product is one of them. A well-thought out list of city dimensions could potentially form a stretched line of distribution of its own kind.

The distribution of normalized revenue was plotted with a scatter chart (Figure 81). The distribution of cities followed more closely the trend line than Gross Domestic Product. A tripartite city arrangement was also reflected clearly in the plot, with Shanghai, Nanjing, and Hangzhou leading the rest of the cities by substantial margins.

The distribution of normalized revenue was plotted with a scatter chart (Figure 82). The distribution of cities followed the trend line closely. The only obvious deviation occurred in the top five to six cities, regarded here as tier one, which exhibited a small positive margin than expected.

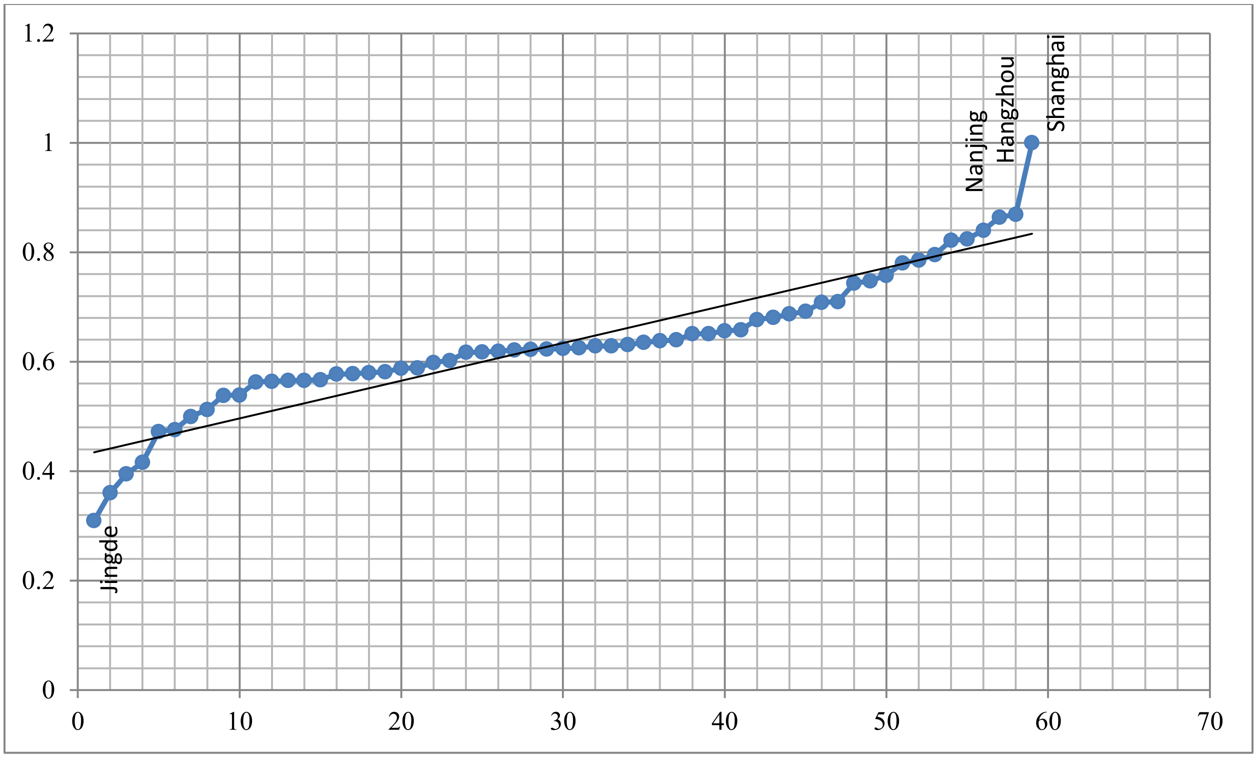


Figure 80. Gross domestic product of 62 cities and towns in Changjiang Delta Region, 2010.

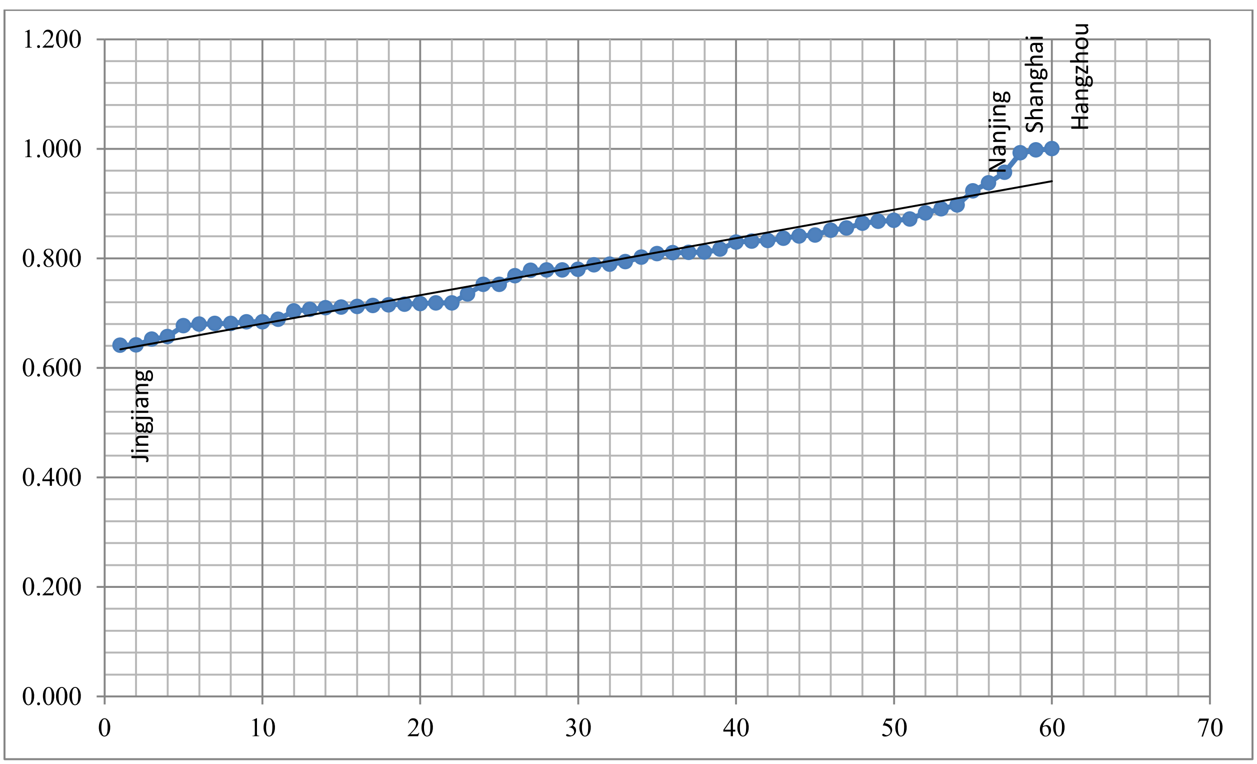


Figure 81. Revenue of 62 cities and towns in Changjiang Delta Region, 2010.

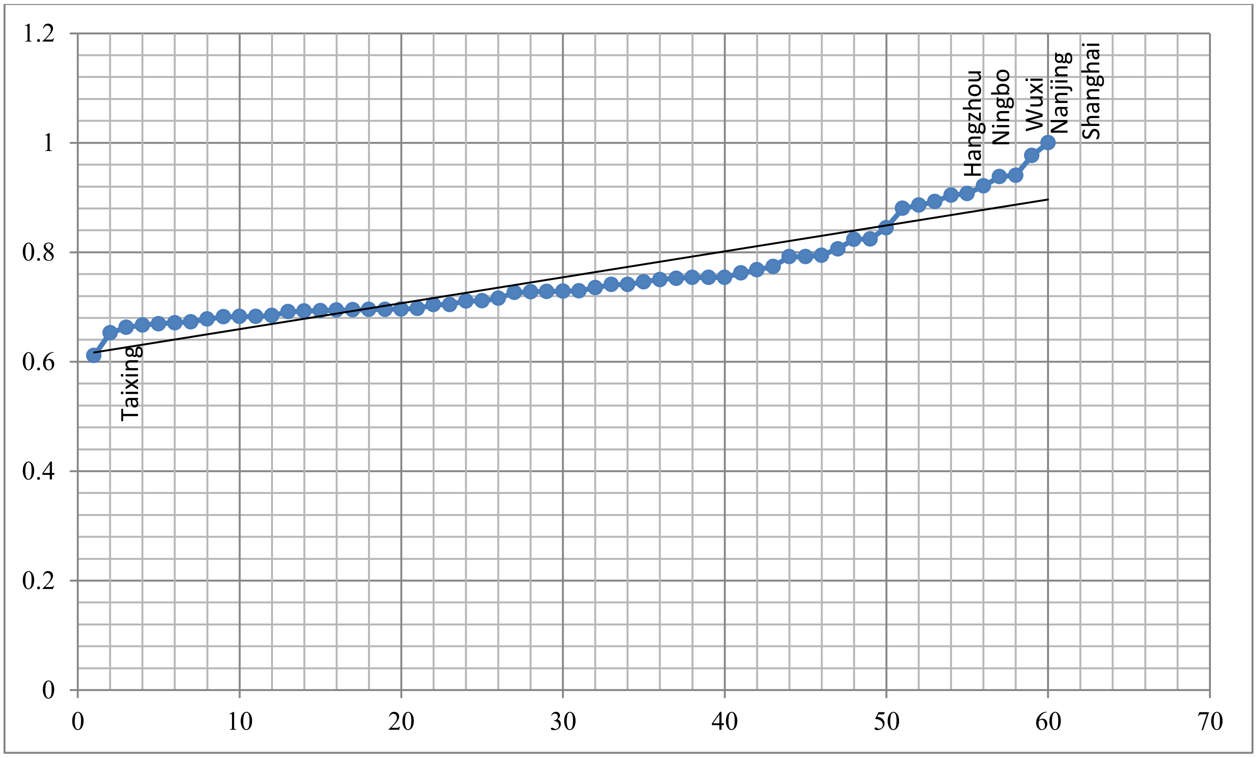


Figure 82. Investment of 62 cities and towns in Changjiang Delta Region, 2010.

One common feature was the well-fitted trend line of investment and revenue, even more so than Gross Domestic Product. The implication was that the cities and towns in the Changjiang Delta Region in 2010, in terms of economic performance, were following a hierarchical order. This order represented certain connections within the urban network, gravity of population, linkage of transit, and clustering of capital, to name a few. Figure 83, revealed that the economic power of the cities can be categorized into four tiers. The first tier included six cities: Shanghai, Nanjing, Hangzhou, Suzhou, Ningbo, and Wuxi with scores ranging from 0.887 to one with Shanghai outperforming the rest of the cities by a large margin. The second tier started with Changzhou at 8th place and ended around Shangyu at 28th place. The third tier was from 29th to 58th place, and the rest fell to the fourth tier.

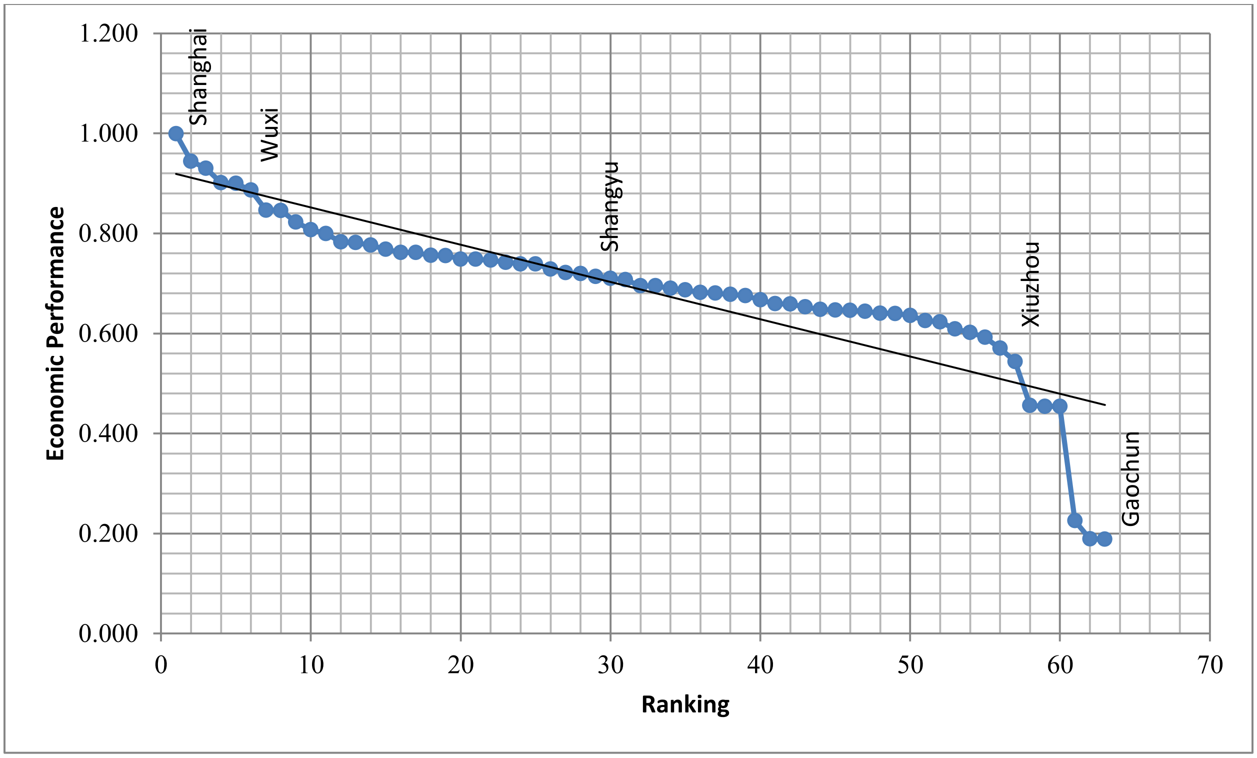


Figure 83. Economic performance scores and rankings.

Again, the plot showed the relative relationship among the cities and towns, and was represented by rankings within the selected boundaries. If the networked region were to expand, then the normalization and scoring system should be reevaluated. Even though the absolute numbers of variables at certain years may stay the same, the relative position of those numbers may shift. Moreover, it could help to better understand the networked region as a whole by comparing neighboring cities and towns, or urban networks. This could be pursued in a separate research endeavor.

Urban growth predictions at a city-level

i. Scenario 1: development corridors.

The results of city-level urban growth prediction are reproduced here. Figures 84, 85, and 86 showed the urban growth prediction outcomes from scenario 1: development corridors by city from 2016 to 2030. (The data from 2011 to 2015 are not presented here). Table 14 shows scenario 1: development corridors urban growth prediction by city, Table 15 shows the urban growth prediction data processed using natural logarithms, and Table 16 shows the normalization of the urban growth prediction.

During the prediction period, the urbanization area, represented by grid pixels, of each city grew at different rate. Some cities outgrew others during this period, especially those in the second and third tiers. The line shape of the logarithmic ranking of the cities revealed a trend of smoothing out the ‘bumps’ in the middle, indicating rank-order changes, following the rule of the development corridors setting of the Scenario Cellular Automata model.

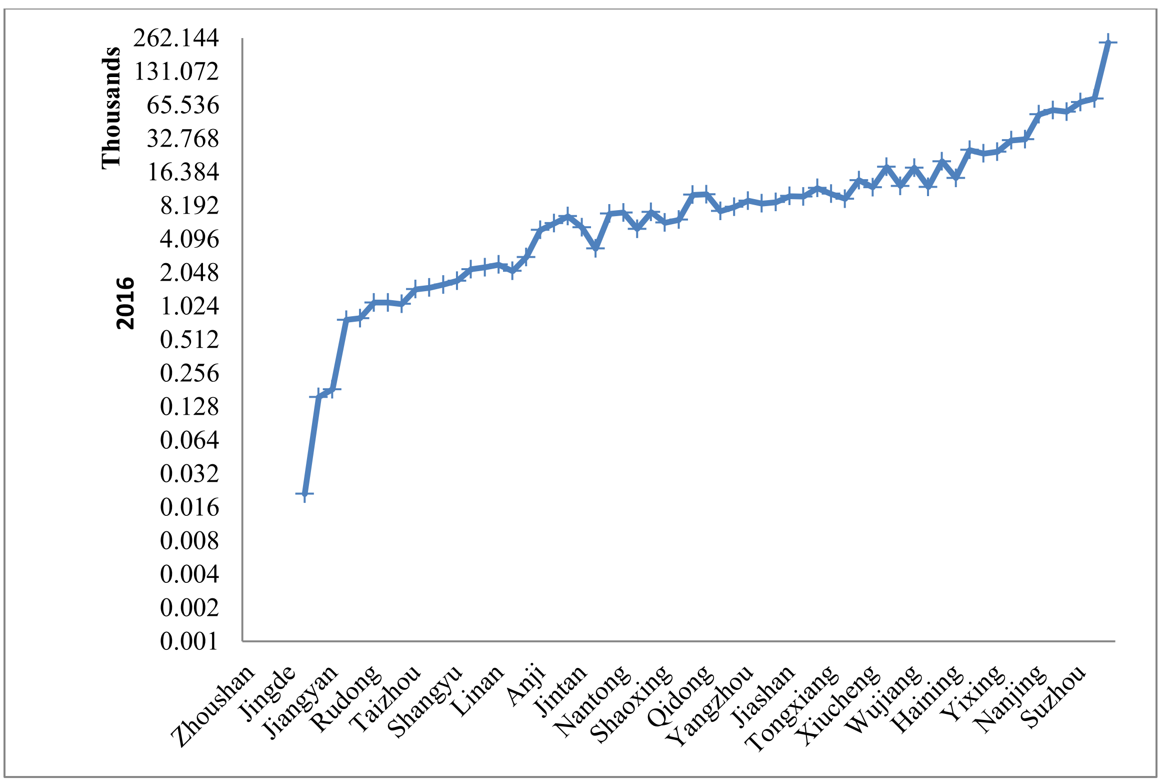


Figure 84. Logarithmic ranking of cities and towns, 2016, scenario 1: development corridors.

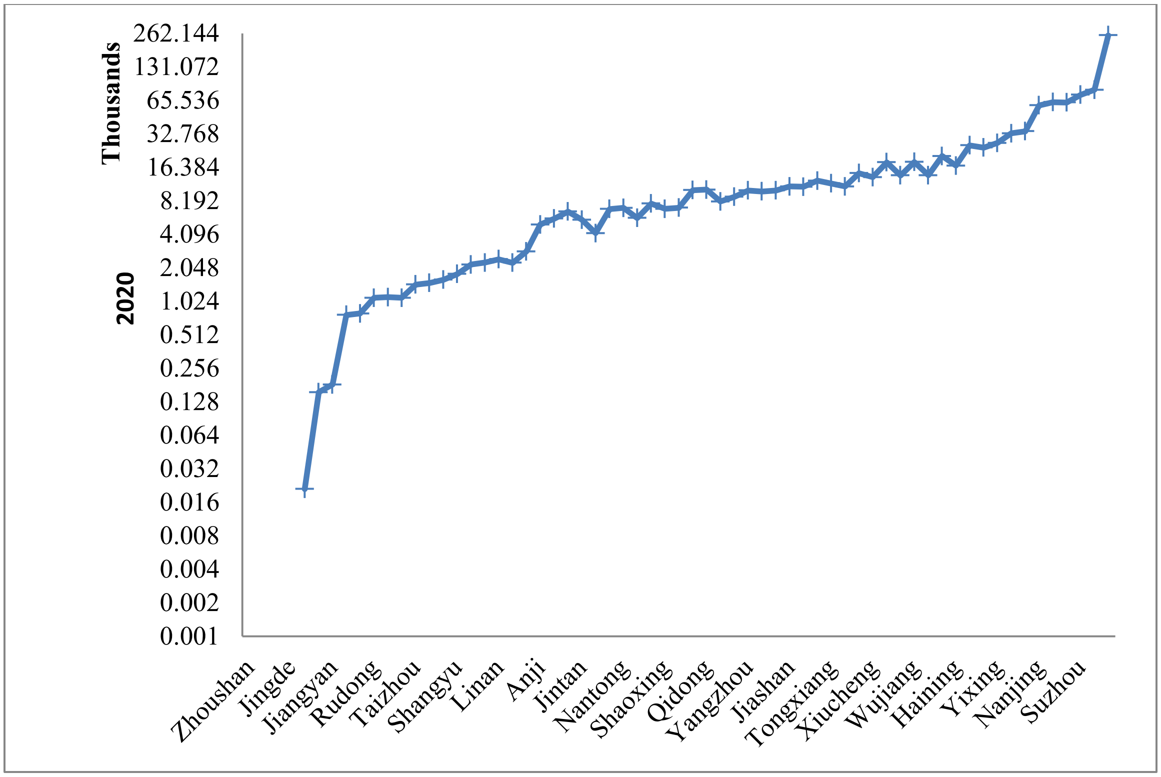


Figure 85. Logarithmic ranking of cities and towns, 2020, scenario 1: development corridors.

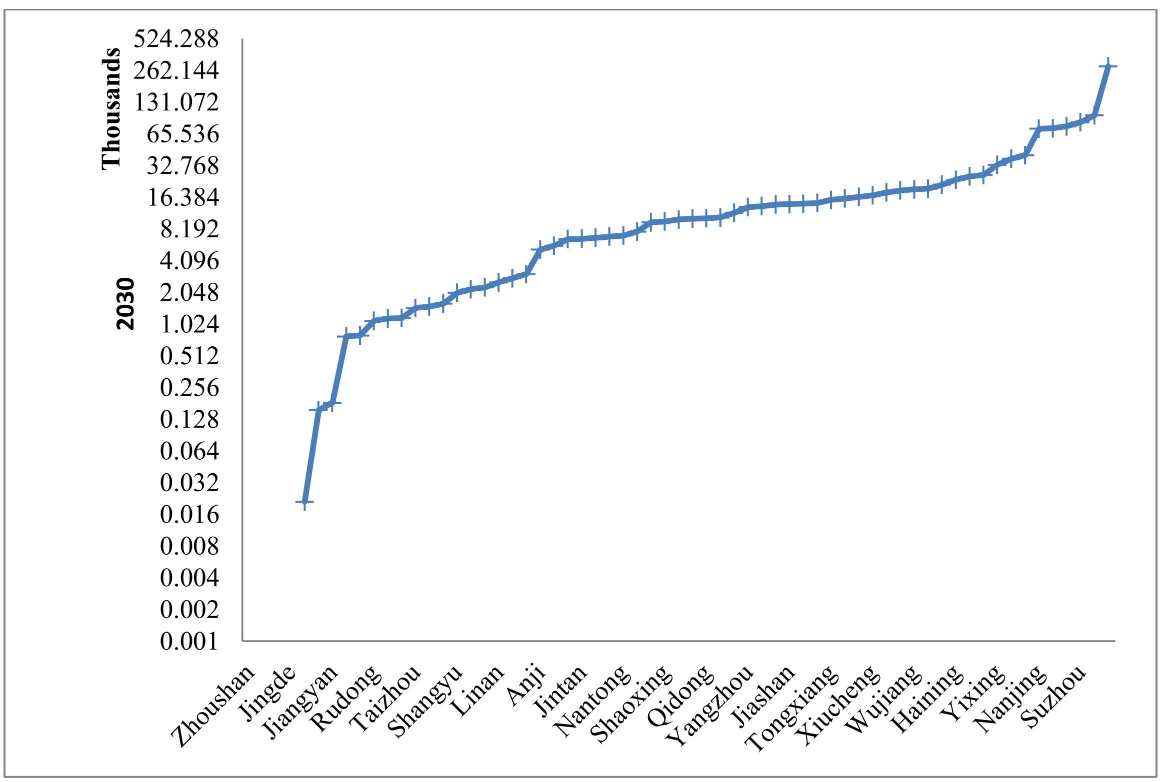


Figure 86. Logarithmic ranking of cities and towns, 2030, scenario 1: development corridors.

City	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Zhoushan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wuxi	58804	59841	60894	62010	63102	64159	65238	66337	67425	68530	69586	70613	71633	72764	73841
Changzhou	56970	58408	59869	61293	62763	64193	65658	67117	68525	69921	71357	72781	74174	75555	76918
Shanghai	238304	241643	245041	248232	251652	255022	258495	261911	265357	268636	272073	275348	278666	281927	285126
Ningbo	2110	2147	2193	2232	2272	2325	2379	2418	2462	2525	2571	2623	2667	2730	2777
Suzhou	69477	70526	71522	72534	73584	74605	75715	76778	77851	78924	79985	81019	82045	83066	84094
Zhenjiang	12243	12627	13018	13463	13854	14301	14741	15235	15711	16219	16691	17257	17783	18347	18960
Nanjing	53825	55103	56389	57629	58961	60283	61668	63000	64378	65754	67107	68540	69984	71414	72891
Nantong	7064	7064	7064	7064	7064	7064	7064	7064	7064	7064	7064	7064	7064	7064	7064
Hangzhou	74675	76370	78062	79685	81406	83101	84760	86442	88053	89698	91284	92976	94556	96175	97738
Shaoxing	5748	6028	6332	6619	6921	7187	7491	7780	8072	8333	8608	8889	9145	9387	9629
Lishui	5038	5200	5364	5558	5747	5930	6126	6311	6515	6706	6937	7135	7335	7527	7723
Gaochun	2818	2829	2847	2857	2870	2883	2903	2918	2931	2948	2964	2985	3002	3024	3044
Jiangyin	31484	31874	32260	32688	33117	33549	34014	34449	34933	35404	35887	36371	36856	37335	37825
Yixing	24869	25403	25967	26495	27096	27656	28244	28850	29463	30048	30661	31270	31923	32578	33200
Liyang	9396	9794	10191	10606	11035	11476	11940	12384	12825	13277	13770	14321	14844	15402	15913
Jintan	5211	5294	5361	5437	5526	5611	5701	5800	5893	5997	6095	6221	6339	6463	6580
Changshu	20386	20464	20531	20600	20676	20753	20833	20917	20989	21074	21144	21237	21317	21411	21514
ngjiagang	25788	25788	25788	25788	25788	25788	25788	25788	25788	25788	25788	25788	25788	25788	25788
Kunshan	32213	32781	33386	33978	34541	35140	35782	36386	37039	37656	38287	38979	39624	40288	40939
Wujiang	17861	17967	18071	18194	18316	18435	18552	18656	18761	18875	18977	19086	19193	19315	19420
Taicang	11741	11895	12069	12253	12428	12606	12806	13007	13203	13397	13589	13793	13998	14204	14404
Rudong	1099	1099	1099	1099	1099	1099	1099	1099	1099	1099	1099	1099	1099	1099	1099
Qidong	10302	10302	10302	10302	10302	10302	10302	10302	10302	10302	10302	10302	10302	10302	10302
Rugao	5666	5666	5666	5666	5666	5666	5666	5666	5666	5666	5666	5666	5666	5666	5666
Tongzhou	18186	18186	18186	18186	18186	18186	18186	18186	18186	18186	18186	18186	18186	18186	18186
Haimen	10222	10222	10222	10222	10222	10222	10222	10222	10222	10222	10222	10222	10222	10222	10222
Yangzhou	9044	9314	9589	9875	10157	10422	10711	10992	11285	11586	11883	12194	12498	12811	13145
Yizheng	8768	9117	9457	9804	10140	10515	10885	11251	11614	11978	12348	12717	13108	13518	13916
Jiangdu	796	796	796	796	796	796	796	796	796	796	796	796	796	796	796
Danyang	11997	12463	12950	13431	13915	14451	14989	15534	16083	16694	17253	17885	18478	19079	19709
Yangzhong	2281	2281	2281	2281	2281	2281	2281	2281	2281	2281	2281	2281	2281	2281	2281
Jurong	6086	6319	6563	6820	7094	7357	7636	7922	8213	8526	8817	9111	9419	9717	10062
Taizhou	1449	1449	1449	1449	1449	1449	1449	1449	1449	1449	1449	1449	1449	1449	1449
Jingjiang	6544	6545	6546	6547	6548	6548	6550	6550	6550	6551	6551	6551	6551	6552	6555
Taixing	6920	6920	6920	6920	6920	6920	6920	6920	6920	6920	6920	6920	6920	6920	6920
Jiangyan	183	183	183	183	183	183	183	183	183	183	183	183	183	183	183
Fuyang	1067	1073	1080	1091	1101	1109	1119	1127	1135	1146	1151	1156	1156	1159	1163
Linan	2409	2411	2423	2438	2444	2459	2472	2481	2488	2497	2507	2521	2526	2533	2542
Yuyao	8530	8882	9238	9583	9939	10268	10646	11009	11365	11724	12093	12442	12781	13127	13457
Cixi	23969	24151	24310	24463	24662	24879	25072	25265	25458	25665	25865	26061	26243	26420	26566
Xiucheng	11939	12286	12615	12976	13336	13705	14090	14425	14808	15178	15537	15920	16281	16664	17055
Xiuzhou	9833	10104	10405	10669	10945	11275	11577	11886	12218	12544	12874	13208	13523	13868	14193
Jiashan	9945	10210	10469	10751	11024	11300	11600	11917	12201	12503	12825	13139	13457	13780	14094
Haiyan	3361	3565	3760	3954	4185	4374	4607	4859	5096	5341	5595	5870	6153	6426	6720
Haining	14448	15035	15698	16309	16933	17569	18252	18941	19606	20310	20993	21720	22459	23184	23939
Pinghu	7277	7477	7656	7856	8073	8280	8525	8743	8982	9247	9473	9722	9982	10259	10493
Tongxiang	10416	10742	11069	11399	11737	12081	12430	12768	13111	13486	13845	14231	14621	15009	15406
Huzhou	13805	13965	14131	14312	14489	14674	14852	15051	15228	15429	15613	15806	16007	16220	16457
Deqing	7131	7268	7414	7564	7722	7893	8063	8224	8392	8555	8730	8906	9098	9293	9460
Changxing	7941	8160	8382	8619	8889	9124	9369	9606	9846	10109	10392	10664	10970	11288	11596
Anji	4936	4953	4968	4990	5015	5032	5049	5063	5083	5102	5123	5137	5157	5178	5197
Shangyu	1726	1747	1759	1779	1801	1815	1833	1858	1878	1901	1919	1948	1972	2004	2022
Wuhu	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21
Xiangshan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dangtu	1101	1108	1109	1110	1113	1120	1122	1125	1127	1128	1131	1135	1140	1146	1151
Xuancheng	2189	2189	2189	2189	2189	2189	2189	2189	2189	2189	2189	2189	2189	2189	2189
Langxi	769	769	771	772	772	773	773	774	774	775	775	777	778	779	779
Guangde	1596	1597	1597	1597	1597	1597	1597	1597	1597	1597	1597	1597	1597	1597	1597
Jingxian	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Jixi	156	156	156	156	156	156	156	156	156	156	156	156	156	156	156
Jingde	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ningguo	1495	1495	1495	1495	1495	1495	1495	1495	1495	1495	1495	1495	1495	1495	1495

Table 14. Scenario 1: development corridors urban growth prediction by city, 2016-2030.

City	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Zhoushan	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Wuxi	10.9820	10.9994	11.0169	11.0351	11.0525	11.0691	11.0858	11.1025	11.1188	11.1350	11.1503	11.1650	11.1793	11.1950	11.2097
Changzhou	10.9503	10.9752	10.9999	11.0234	11.0471	11.0696	11.0922	11.1142	11.1350	11.1551	11.1755	11.1952	11.2142	11.2326	11.2505
Shanghai	12.3813	12.3952	12.4092	12.4221	12.4358	12.4491	12.4626	12.4758	12.4888	12.5011	12.5138	12.5258	12.5378	12.5494	12.5607
Ningbo	7.6544	7.6718	7.6930	7.7107	7.7284	7.7515	7.7744	7.7907	7.8087	7.8340	7.8521	7.8721	7.8887	7.9121	7.9291
Suzhou	11.1488	11.1637	11.1778	11.1918	11.2062	11.2200	11.2347	11.2487	11.2626	11.2762	11.2896	11.3024	11.3150	11.3274	11.3397
Zhenjiang	9.4127	9.4436	9.4741	9.5077	9.5363	9.5681	9.5984	9.6314	9.6621	9.6939	9.7226	9.7560	9.7860	9.8172	9.8501
Nanjing	10.8935	10.9170	10.9400	10.9618	10.9846	11.0068	11.0295	11.0509	11.0725	11.0937	11.1140	11.1352	11.1560	11.1762	11.1967
Nantong	8.8628	8.8628	8.8628	8.8628	8.8628	8.8628	8.8628	8.8628	8.8628	8.8628	8.8628	8.8628	8.8628	8.8628	8.8628
Hangzhou	11.2209	11.2433	11.2653	11.2858	11.3072	11.3278	11.3476	11.3672	11.3857	11.4042	11.4217	11.4401	11.4569	11.4739	11.4900
Shaoxing	8.6566	8.7042	8.7534	8.7977	8.8423	8.8800	8.9215	8.9593	8.9962	9.0280	9.0604	9.0926	9.1210	9.1471	9.1725
Lishui	8.5248	8.5564	8.5875	8.6230	8.6564	8.6878	8.7203	8.7500	8.7819	8.8108	8.8446	8.8728	8.9004	8.9263	8.9520
Gaochun	7.9438	7.9477	7.9540	7.9575	7.9621	7.9666	7.9735	7.9787	7.9831	7.9889	7.9943	8.0014	8.0070	8.0143	8.0209
Jiangyin	10.3572	10.3695	10.3816	10.3948	10.4078	10.4208	10.4345	10.4472	10.4612	10.4746	10.4881	10.5015	10.5148	10.5277	10.5407
Yixing	10.1214	10.1426	10.1646	10.1847	10.2071	10.2276	10.2486	10.2699	10.2909	10.3106	10.3307	10.3504	10.3711	10.3914	10.4103
Liyang	9.1480	9.1895	9.2293	9.2692	9.3088	9.3480	9.3876	9.4242	9.4592	9.4938	9.5302	9.5695	9.6054	9.6423	9.6749
Jintan	8.5585	8.5743	8.5869	8.6010	8.6172	8.6325	8.6484	8.6656	8.6815	8.6990	8.7152	8.7357	8.7545	8.7738	8.7918
Changshu	9.9226	9.9264	9.9297	9.9330	9.9367	9.9404	9.9443	9.9483	9.9518	9.9558	9.9591	9.9635	9.9673	9.9717	9.9765
ngjiagang	10.1577	10.1577	10.1577	10.1577	10.1577	10.1577	10.1577	10.1577	10.1577	10.1577	10.1577	10.1577	10.1577	10.1577	10.1577
Kunshan	10.3801	10.3976	10.4159	10.4335	10.4499	10.4671	10.4852	10.5019	10.5197	10.5362	10.5529	10.5708	10.5872	10.6038	10.6198
Wujiang	9.7904	9.7963	9.8021	9.8088	9.8155	9.8220	9.8283	9.8339	9.8395	9.8456	9.8510	9.8567	9.8623	9.8686	9.8741
Taicang	9.3708	9.3839	9.3984	9.4135	9.4277	9.4419	9.4577	9.4732	9.4882	9.5028	9.5170	9.5319	9.5467	9.5613	9.5753
Rudong	7.0022	7.0022	7.0022	7.0022	7.0022	7.0022	7.0022	7.0022	7.0022	7.0022	7.0022	7.0022	7.0022	7.0022	7.0022
Qidong	9.2401	9.2401	9.2401	9.2401	9.2401	9.2401	9.2401	9.2401	9.2401	9.2401	9.2401	9.2401	9.2401	9.2401	9.2401
Rugao	8.6422	8.6422	8.6422	8.6422	8.6422	8.6422	8.6422	8.6422	8.6422	8.6422	8.6422	8.6422	8.6422	8.6422	8.6422
Tongzhou	9.8084	9.8084	9.8084	9.8084	9.8084	9.8084	9.8084	9.8084	9.8084	9.8084	9.8084	9.8084	9.8084	9.8084	9.8084
Haimen	9.2323	9.2323	9.2323	9.2323	9.2323	9.2323	9.2323	9.2323	9.2323	9.2323	9.2323	9.2323	9.2323	9.2323	9.2323
Yangzhou	9.1099	9.1393	9.1684	9.1978	9.2259	9.2517	9.2790	9.3049	9.3312	9.3576	9.3829	9.4087	9.4333	9.4581	9.4838
Yizheng	9.0789	9.1179	9.1545	9.1905	9.2242	9.2606	9.2951	9.3282	9.3600	9.3908	9.4212	9.4507	9.4810	9.5118	9.5408
Jiangdu	6.6796	6.6796	6.6796	6.6796	6.6796	6.6796	6.6796	6.6796	6.6796	6.6796	6.6796	6.6796	6.6796	6.6796	6.6796
Danyang	9.3924	9.4305	9.4689	9.5053	9.5407	9.5785	9.6151	9.6508	9.6855	9.7228	9.7557	9.7917	9.8243	9.8563	9.8888
Yangzhong	7.7324	7.7324	7.7324	7.7324	7.7324	7.7324	7.7324	7.7324	7.7324	7.7324	7.7324	7.7324	7.7324	7.7324	7.7324
Jurong	8.7137	8.7513	8.7892	8.8276	8.8670	8.9034	8.9406	8.9774	9.0135	9.0509	9.0844	9.1172	9.1505	9.1816	9.2165
Taizhou	7.2786	7.2786	7.2786	7.2786	7.2786	7.2786	7.2786	7.2786	7.2786	7.2786	7.2786	7.2786	7.2786	7.2786	7.2786
Jingjiang	8.7863	8.7865	8.7866	8.7868	8.7869	8.7869	8.7872	8.7872	8.7872	8.7874	8.7874	8.7874	8.7874	8.7875	8.7880
Taixing	8.8422	8.8422	8.8422	8.8422	8.8422	8.8422	8.8422	8.8422	8.8422	8.8422	8.8422	8.8422	8.8422	8.8422	8.8422
Jiangyan	5.2095	5.2095	5.2095	5.2095	5.2095	5.2095	5.2095	5.2095	5.2095	5.2095	5.2095	5.2095	5.2095	5.2095	5.2095
Fuyang	6.9726	6.9782	6.9847	6.9948	7.0040	7.0112	7.0202	7.0273	7.0344	7.0440	7.0484	7.0527	7.0527	7.0553	7.0588
Linan	7.7870	7.7878	7.7928	7.7989	7.8014	7.8075	7.8128	7.8164	7.8192	7.8228	7.8268	7.8324	7.8344	7.8372	7.8407
Yuyao	9.0513	9.0918	9.1311	9.1677	9.2042	9.2368	9.2729	9.3065	9.3383	9.3694	9.4004	9.4288	9.4557	9.4824	9.5073
Cixi	10.0845	10.0921	10.0986	10.1049	10.1130	10.1218	10.1295	10.1372	10.1448	10.1529	10.1606	10.1682	10.1752	10.1819	10.1874
Xiucheng	9.3876	9.4162	9.4426	9.4709	9.4982	9.5255	9.5532	9.5767	9.6029	9.6276	9.6510	9.6753	9.6978	9.7210	9.7442
Xiuzhou	9.1935	9.2207	9.2500	9.2751	9.3006	9.3303	9.3568	9.3831	9.4107	9.4370	9.4630	9.4886	9.5121	9.5373	9.5605
Jiashan	9.2048	9.2311	9.2562	9.2828	9.3078	9.3326	9.3588	9.3857	9.4093	9.4337	9.4592	9.4833	9.5073	9.5310	9.5535
Haiyan	8.1200	8.1789	8.2322	8.2825	8.3393	8.3834	8.4353	8.4886	8.5362	8.5832	8.6296	8.6776	8.7247	8.7681	8.8128
Haining	9.5783	9.6181	9.6613	9.6995	9.7370	9.7739	9.8120	9.8491	9.8836	9.9189	9.9519	9.9860	10.0194	10.0512	10.0833
Pinghu	8.8925	8.9196	8.9432	8.9690	8.9963	9.0216	9.0508	9.0760	9.1030	9.1321	9.1562	9.1821	9.2085	9.2359	9.2585
Tongxiang	9.2511	9.2819	9.3119	9.3413	9.3705	9.3994	9.4279	9.4547	9.4812	9.5094	9.5357	9.5632	9.5902	9.6164	9.6425
Huzhou	9.5328	9.5443	9.5561	9.5689	9.5811	9.5938	9.6059	9.6192	9.6309	9.6440	9.6559	9.6681	9.6808	9.6940	9.7085
Deqing	8.8722	8.8912	8.9111	8.9312	8.9518	8.9737	8.9950	9.0148	9.0350	9.0543	9.0745	9.0945	9.1158	9.1370	9.1548
Changxing	8.9798	9.0070	9.0338	9.0617	9.0926	9.1187	9.1452	9.1701	9.1948	9.2212	9.2488	9.2746	9.3029	9.3315	9.3584
Anji	8.5043	8.5077	8.5108	8.5152	8.5202	8.5236	8.5269	8.5297	8.5337	8.5374	8.5415	8.5442	8.5481	8.5522	8.5558
Shangyu	7.4536	7.4657	7.4725	7.4838	7.4961	7.5038	7.5137	7.5273	7.5380	7.5501	7.5596	7.5746	7.5868	7.6029	7.6118
Wuhu	3.0445	3.0445	3.0445	3.0445	3.0445	3.0445	3.0445	3.0445	3.0445	3.0445	3.0445	3.0445	3.0445	3.0445	3.0445
Xiangshan	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Dangtu	7.0040	7.0103	7.0112	7.0121	7.0148	7.0211	7.0229	7.0255	7.0273	7.0282	7.0309	7.0344	7.0388	7.0440	7.0484
Xuancheng	7.6912	7.6912	7.6912	7.6912	7.6912	7.6912	7.6912	7.6912	7.6912	7.6912	7.6912	7.6912	7.6912	7.6912	7.6912
Langxi	6.6451	6.6451	6.6477	6.6490	6.6490	6.6503	6.6503	6.6516	6.6516	6.6529	6.6529	6.6554	6.6567	6.6580	6.6580
Guangde	7.3753	7.3759	7.3759	7.3759	7.3759	7.3759	7.3759	7.3759	7.3759	7.3759	7.3759	7.3759	7.3759	7.3759	7.3759
Jingxian	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Jixi	5.0499	5.0499	5.0499	5.0499	5.0499	5.0499	5.0499	5.0499	5.0499	5.0499	5.0499	5.0499	5.0499	5.0499	5.0499
Jingde	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ningguo	7.3099	7.3099	7.3099	7.3099	7.3099	7.3099	7.3099	7.3099	7.3099	7.3099	7.3099	7.3099	7.3099	7.3099	7.3099

Table 15. Natural logarithm of scenario 1: development corridors urban growth prediction by city, 2016-2030.

City	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Zhoushan	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Wuxi	0.8870	0.8874	0.8878	0.8883	0.8888	0.8891	0.8895	0.8899	0.8903	0.8907	0.8910	0.8914	0.8917	0.8921	0.8924
Changzhou	0.8844	0.8854	0.8864	0.8874	0.8883	0.8892	0.8900	0.8909	0.8916	0.8923	0.8930	0.8938	0.8944	0.8951	0.8957
Shanghai	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Ningbo	0.6182	0.6189	0.6199	0.6207	0.6215	0.6227	0.6238	0.6245	0.6253	0.6267	0.6275	0.6285	0.6292	0.6305	0.6313
Suzhou	0.9005	0.9006	0.9008	0.9010	0.9011	0.9013	0.9015	0.9016	0.9018	0.9020	0.9022	0.9023	0.9025	0.9026	0.9028
Zhenjiang	0.7602	0.7619	0.7635	0.7654	0.7668	0.7686	0.7702	0.7720	0.7737	0.7754	0.7770	0.7789	0.7805	0.7823	0.7842
Nanjing	0.8798	0.8807	0.8816	0.8824	0.8833	0.8841	0.8850	0.8858	0.8866	0.8874	0.8881	0.8890	0.8898	0.8906	0.8914
Nantong	0.7158	0.7150	0.7142	0.7135	0.7127	0.7119	0.7111	0.7104	0.7097	0.7090	0.7082	0.7076	0.7069	0.7062	0.7056
Hangzhou	0.9063	0.9071	0.9078	0.9085	0.9092	0.9099	0.9105	0.9111	0.9117	0.9123	0.9127	0.9133	0.9138	0.9143	0.9148
Shaoxing	0.6992	0.7022	0.7054	0.7082	0.7110	0.7133	0.7159	0.7181	0.7203	0.7222	0.7240	0.7259	0.7275	0.7289	0.7303
Lishui	0.6885	0.6903	0.6920	0.6942	0.6961	0.6979	0.6997	0.7014	0.7032	0.7048	0.7068	0.7084	0.7099	0.7113	0.7127
Gaochun	0.6416	0.6412	0.6410	0.6406	0.6403	0.6399	0.6398	0.6395	0.6392	0.6391	0.6388	0.6388	0.6386	0.6386	0.6386
Jiangyin	0.8365	0.8366	0.8366	0.8368	0.8369	0.8371	0.8373	0.8374	0.8376	0.8379	0.8381	0.8384	0.8386	0.8389	0.8392
Yixing	0.8175	0.8183	0.8191	0.8199	0.8208	0.8216	0.8223	0.8232	0.8240	0.8248	0.8255	0.8263	0.8272	0.8280	0.8288
Liyang	0.7389	0.7414	0.7437	0.7462	0.7486	0.7509	0.7533	0.7554	0.7574	0.7594	0.7616	0.7640	0.7661	0.7683	0.7703
Jintan	0.6912	0.6917	0.6920	0.6924	0.6929	0.6934	0.6939	0.6946	0.6951	0.6959	0.6964	0.6974	0.6982	0.6991	0.6999
Changshu	0.8014	0.8008	0.8002	0.7996	0.7990	0.7985	0.7979	0.7974	0.7969	0.7964	0.7958	0.7954	0.7950	0.7946	0.7943
Zhangjiagang	0.8204	0.8195	0.8186	0.8177	0.8168	0.8159	0.8150	0.8142	0.8133	0.8125	0.8117	0.8109	0.8102	0.8094	0.8087
Kunshan	0.8384	0.8388	0.8394	0.8399	0.8403	0.8408	0.8413	0.8418	0.8423	0.8428	0.8433	0.8439	0.8444	0.8450	0.8455
Wujiang	0.7907	0.7903	0.7899	0.7896	0.7893	0.7890	0.7886	0.7882	0.7879	0.7876	0.7872	0.7869	0.7866	0.7864	0.7861
Taicang	0.7569	0.7571	0.7574	0.7578	0.7581	0.7584	0.7589	0.7593	0.7597	0.7602	0.7605	0.7610	0.7614	0.7619	0.7623
Rudong	0.5655	0.5649	0.5643	0.5637	0.5631	0.5625	0.5619	0.5613	0.5607	0.5601	0.5596	0.5590	0.5585	0.5580	0.5575
Qidong	0.7463	0.7455	0.7446	0.7438	0.7430	0.7422	0.7414	0.7406	0.7399	0.7391	0.7384	0.7377	0.7370	0.7363	0.7356
Rugao	0.6980	0.6972	0.6964	0.6957	0.6949	0.6942	0.6935	0.6927	0.6920	0.6913	0.6906	0.6900	0.6893	0.6887	0.6880
Tongzhou	0.7922	0.7913	0.7904	0.7896	0.7887	0.7879	0.7870	0.7862	0.7854	0.7846	0.7838	0.7831	0.7823	0.7816	0.7809
Haimen	0.7457	0.7448	0.7440	0.7432	0.7424	0.7416	0.7408	0.7400	0.7392	0.7385	0.7378	0.7371	0.7364	0.7357	0.7350
Yangzhou	0.7358	0.7373	0.7388	0.7404	0.7419	0.7432	0.7445	0.7458	0.7472	0.7485	0.7498	0.7511	0.7524	0.7537	0.7550
Yizheng	0.7333	0.7356	0.7377	0.7399	0.7417	0.7439	0.7458	0.7477	0.7495	0.7512	0.7529	0.7545	0.7562	0.7579	0.7596
Jiangdu	0.5395	0.5389	0.5383	0.5377	0.5371	0.5366	0.5360	0.5354	0.5348	0.5343	0.5338	0.5333	0.5328	0.5323	0.5318
Danyang	0.7586	0.7608	0.7631	0.7652	0.7672	0.7694	0.7715	0.7736	0.7755	0.7778	0.7796	0.7817	0.7836	0.7854	0.7873
Yangzhong	0.6245	0.6238	0.6231	0.6225	0.6218	0.6211	0.6204	0.6198	0.6191	0.6185	0.6179	0.6173	0.6167	0.6162	0.6156
Jurong	0.7038	0.7060	0.7083	0.7106	0.7130	0.7152	0.7174	0.7196	0.7217	0.7240	0.7260	0.7279	0.7298	0.7316	0.7338
Taizhou	0.5879	0.5872	0.5866	0.5859	0.5853	0.5847	0.5840	0.5834	0.5828	0.5822	0.5816	0.5811	0.5805	0.5800	0.5795
Jingjiang	0.7096	0.7089	0.7081	0.7073	0.7066	0.7058	0.7051	0.7043	0.7036	0.7029	0.7022	0.7015	0.7009	0.7002	0.6996
Taixing	0.7142	0.7134	0.7126	0.7118	0.7110	0.7103	0.7095	0.7087	0.7080	0.7073	0.7066	0.7059	0.7052	0.7046	0.7040
Jiangyan	0.4208	0.4203	0.4198	0.4194	0.4189	0.4185	0.4180	0.4176	0.4171	0.4167	0.4163	0.4159	0.4155	0.4151	0.4147
Fuyang	0.5632	0.5630	0.5629	0.5631	0.5632	0.5632	0.5633	0.5633	0.5633	0.5635	0.5632	0.5631	0.5625	0.5622	0.5620
Linan	0.6289	0.6283	0.6280	0.6278	0.6273	0.6272	0.6269	0.6265	0.6261	0.6258	0.6255	0.6253	0.6249	0.6245	0.6242
Yuyao	0.7310	0.7335	0.7358	0.7380	0.7401	0.7420	0.7441	0.7460	0.7477	0.7495	0.7512	0.7528	0.7542	0.7556	0.7569
Cixi	0.8145	0.8142	0.8138	0.8135	0.8132	0.8131	0.8128	0.8125	0.8123	0.8122	0.8120	0.8118	0.8116	0.8113	0.8111
Xiucheng	0.7582	0.7597	0.7609	0.7624	0.7638	0.7652	0.7665	0.7676	0.7689	0.7701	0.7712	0.7724	0.7735	0.7746	0.7758
Xiuzhou	0.7425	0.7439	0.7454	0.7467	0.7479	0.7495	0.7508	0.7521	0.7535	0.7549	0.7562	0.7575	0.7587	0.7600	0.7611
Jiashan	0.7434	0.7447	0.7459	0.7473	0.7485	0.7497	0.7509	0.7523	0.7534	0.7546	0.7559	0.7571	0.7583	0.7595	0.7606
Haiyan	0.6558	0.6598	0.6634	0.6668	0.6706	0.6734	0.6768	0.6804	0.6835	0.6866	0.6896	0.6928	0.6959	0.6987	0.7016
Haining	0.7736	0.7760	0.7786	0.7808	0.7830	0.7851	0.7873	0.7895	0.7914	0.7934	0.7953	0.7972	0.7991	0.8009	0.8028
Pinghu	0.7182	0.7196	0.7207	0.7220	0.7234	0.7247	0.7262	0.7275	0.7289	0.7305	0.7317	0.7331	0.7345	0.7360	0.7371
Tongxiang	0.7472	0.7488	0.7504	0.7520	0.7535	0.7550	0.7565	0.7578	0.7592	0.7607	0.7620	0.7635	0.7649	0.7663	0.7677
Huzhou	0.7699	0.7700	0.7701	0.7703	0.7704	0.7706	0.7708	0.7710	0.7712	0.7715	0.7716	0.7719	0.7721	0.7725	0.7729
Deqing	0.7166	0.7173	0.7181	0.7190	0.7198	0.7208	0.7218	0.7226	0.7234	0.7243	0.7252	0.7261	0.7271	0.7281	0.7288
Changxing	0.7253	0.7267	0.7280	0.7295	0.7312	0.7325	0.7338	0.7350	0.7362	0.7376	0.7391	0.7404	0.7420	0.7436	0.7451
Anji	0.6869	0.6864	0.6858	0.6855	0.6851	0.6847	0.6842	0.6837	0.6833	0.6829	0.6826	0.6821	0.6818	0.6815	0.6812
Shangyu	0.6020	0.6023	0.6022	0.6025	0.6028	0.6028	0.6029	0.6034	0.6036	0.6040	0.6041	0.6047	0.6051	0.6058	0.6060
Wuhu	0.2459	0.2456	0.2453	0.2451	0.2448	0.2446	0.2443	0.2440	0.2438	0.2435	0.2433	0.2431	0.2428	0.2426	0.2424
Xiangshan	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Dangtu	0.5657	0.5656	0.5650	0.5645	0.5641	0.5640	0.5635	0.5631	0.5627	0.5622	0.5618	0.5616	0.5614	0.5613	0.5611
Xuancheng	0.6212	0.6205	0.6198	0.6192	0.6185	0.6178	0.6171	0.6165	0.6158	0.6152	0.6146	0.6140	0.6134	0.6129	0.6123
Langxi	0.5367	0.5361	0.5357	0.5353	0.5347	0.5342	0.5336	0.5332	0.5326	0.5322	0.5316	0.5313	0.5309	0.5305	0.5301
Guangde	0.5957	0.5951	0.5944	0.5938	0.5931	0.5925	0.5918	0.5912	0.5906	0.5900	0.5894	0.5889	0.5883	0.5877	0.5872
Jingxian	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Jixi	0.4079	0.4074	0.4069	0.4065	0.4061	0.4056	0.4052	0.4048	0.4043	0.4040	0.4035	0.4032	0.4028	0.4024	0.4020
Jingde	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ningguo	0.5904	0.5897	0.5891	0.5885	0.5878	0.5872	0.5865	0.5859	0.5853	0.5847	0.5841	0.5836	0.5830	0.5825	0.5820

Table 16. Normalization of scenario 1: development corridors urban growth prediction by city, 2016-2030.

ii. Scenario 2: development corridors, plus big city growth

Again, the results of city-level urban growth prediction were reproduced. Figures 87, 88, and 89 show the urban growth prediction outcomes from scenario 2: development corridors, plus big city growth by city from 2016 to 2030. The Scenario Cellular Automata model was used to predict from 2011 to 2030, but data from 2011 to 2015 were not presented here. Table 13 shows scenario 2: development corridors, plus big city growth urbanization prediction by city, Table 14 shows the urban growth prediction data processed using natural logarithms, and Table 15 shows the normalization of the urban growth prediction.

Once again, during the prediction period, the urbanization area, represented by grid pixels, of each city grew at different rates. Some cities outgrew others during this predicting period, especially for those in the second and third tiers. Again, the line shape of the logarithmic ranking of the cities also revealed a trend of smoothing out the ‘bumps’ in the middle, indicating rank-order changes again following the rule of the development corridors, plus big city growth setting of the Scenario Cellular Automata model.

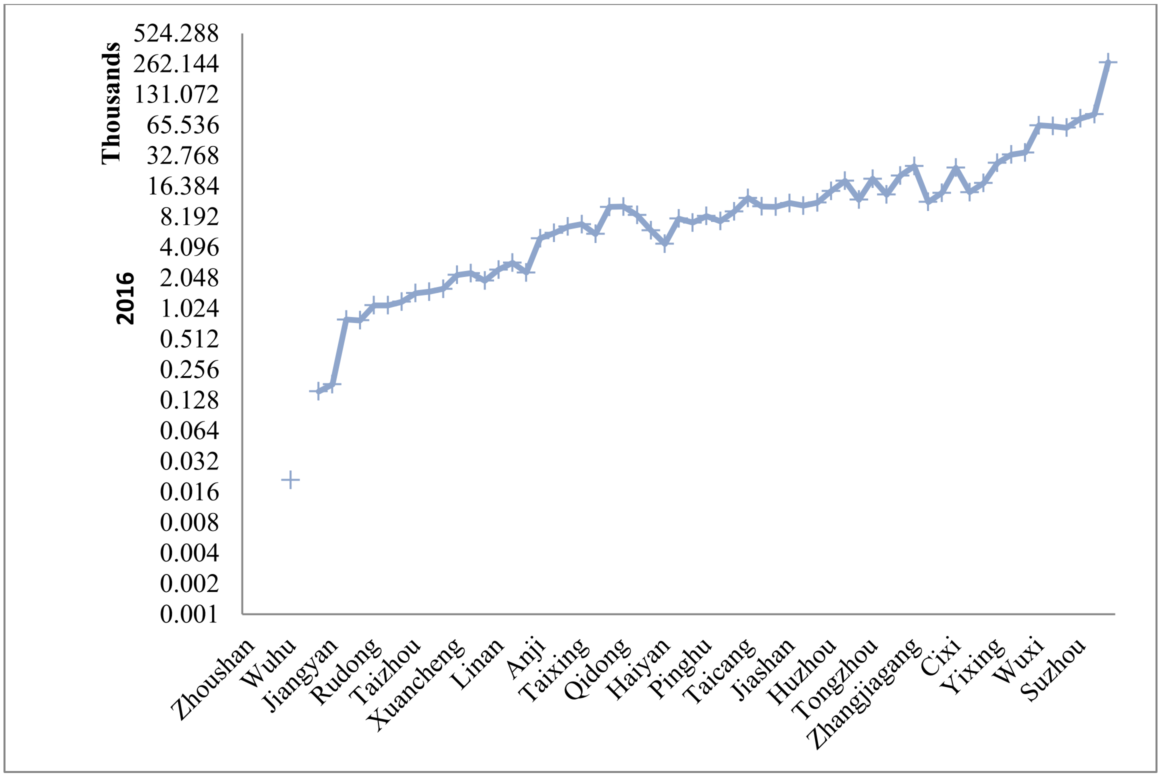


Figure 87. Logarithmic ranking of cities and towns, 2016, scenario 2: development corridors, plus big city growth.

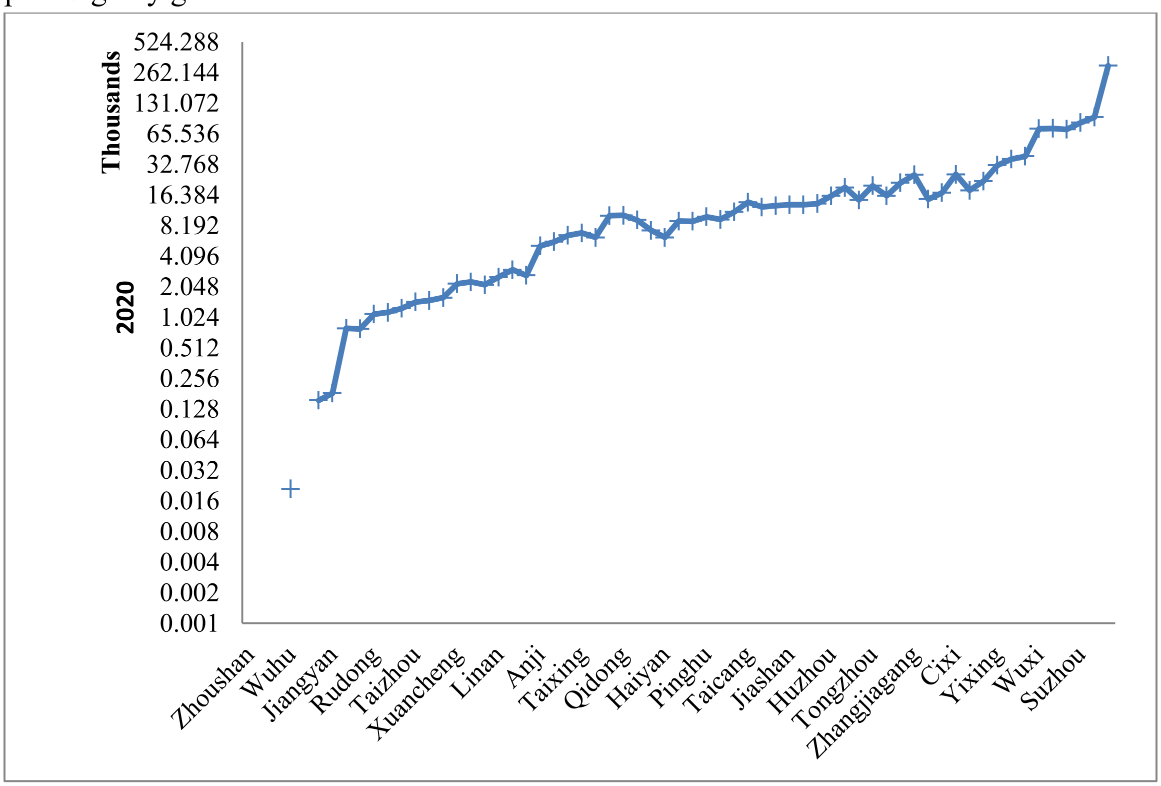


Figure 88. Logarithmic ranking of cities and towns, 2020, scenario 2: development corridors, plus big city growth.

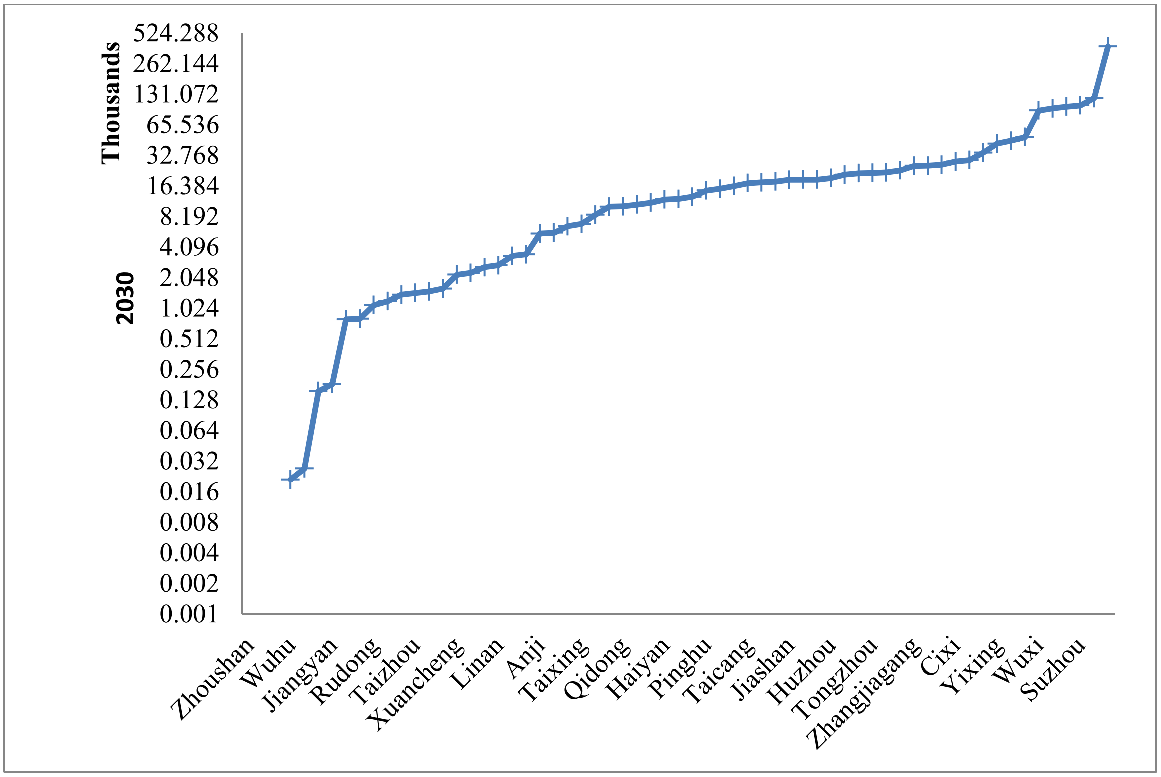


Figure 89. Logarithmic ranking of cities and towns, 2030, scenario 2: development corridors, plus big city growth.

City	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Zhoushan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Jingxian	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Jingde	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wuhu	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21
Xiangshan	0	0	0	0	0	0	0	0	1	1	3	5	9	17	27
Jixi	156	156	156	156	156	156	156	156	156	156	156	156	156	156	156
Jiangyan	183	183	183	183	183	183	183	183	183	183	183	183	183	183	183
Jiangdu	796	796	796	796	796	796	796	796	796	796	796	796	796	796	796
Langxi	781	782	783	785	787	788	789	791	793	796	799	800	801	803	805
Rudong	1099	1099	1099	1099	1099	1099	1099	1099	1099	1099	1099	1099	1099	1099	1099
Fuyang	1100	1115	1124	1136	1145	1153	1158	1162	1169	1177	1181	1185	1188	1192	1198
Dangtu	1192	1209	1219	1230	1251	1270	1288	1307	1324	1338	1348	1362	1374	1381	1390
Taizhou	1449	1449	1449	1449	1449	1449	1449	1449	1449	1449	1449	1449	1449	1449	1449
Ningguo	1495	1495	1495	1495	1495	1495	1495	1495	1495	1495	1495	1495	1495	1495	1495
Guangde	1597	1597	1597	1597	1597	1597	1597	1597	1597	1597	1597	1597	1597	1597	1597
Xuancheng	2189	2189	2189	2189	2189	2189	2189	2189	2189	2189	2189	2189	2189	2189	2189
Yangzhong	2281	2281	2281	2281	2281	2281	2281	2281	2281	2281	2281	2281	2281	2281	2281
Shangyu	1920	1980	2030	2088	2134	2188	2232	2280	2330	2382	2428	2481	2521	2563	2600
Linan	2470	2487	2508	2523	2544	2561	2580	2600	2620	2640	2654	2670	2687	2702	2718
Gaochun	2889	2914	2950	2979	3005	3035	3071	3107	3139	3179	3212	3245	3278	3323	3351
Ningbo	2312	2401	2480	2566	2644	2726	2816	2891	2982	3068	3148	3226	3310	3389	3473
Anji	5019	5059	5089	5124	5159	5193	5233	5264	5301	5338	5371	5419	5467	5514	5555
Rugao	5666	5666	5666	5666	5666	5666	5666	5666	5666	5666	5666	5666	5666	5666	5666
Jingjiang	6545	6546	6547	6547	6548	6549	6552	6556	6558	6560	6560	6563	6565	6567	6567
Taixing	6920	6920	6920	6920	6920	6920	6920	6920	6920	6920	6920	6920	6920	6920	6920
Jintan	5547	5713	5903	6080	6255	6434	6628	6827	7028	7262	7490	7718	7982	8223	8514
Haimen	10222	10222	10222	10222	10222	10222	10223	10223	10223	10223	10223	10224	10225	10228	10232
Qidong	10302	10302	10302	10302	10302	10302	10302	10302	10302	10302	10302	10302	10302	10302	10302
Nantong	8492	8690	8889	9099	9291	9489	9662	9820	9951	10101	10220	10354	10477	10616	10744
Lishui	5999	6330	6662	6988	7334	7708	8085	8490	8883	9259	9640	10031	10402	10798	11202
Haiyan	4435	4854	5322	5781	6247	6750	7293	7839	8409	8999	9583	10174	10804	11423	12060
Deqing	7846	8137	8447	8753	9055	9379	9677	9994	10305	10634	10928	11239	11560	11875	12189
Shaoxing	7170	7651	8131	8582	9027	9491	9925	10344	10759	11140	11517	11861	12203	12522	12819
Pinghu	8312	8679	9107	9547	9962	10414	10846	11326	11798	12271	12750	13254	13751	14264	14783
Jurong	7423	7888	8383	8898	9387	9915	10455	11016	11582	12194	12812	13414	14038	14690	15340
Changxing	9199	9669	10150	10639	11135	11647	12162	12657	13130	13641	14157	14703	15247	15772	16323
Taicang	12553	12874	13211	13555	13901	14276	14660	15009	15348	15694	16047	16388	16725	17093	17448
Yangzhou	10361	10882	11401	11883	12428	12985	13546	14079	14642	15171	15700	16239	16761	17296	17765
Yuyao	10268	10895	11526	12184	12799	13408	13987	14564	15117	15651	16149	16660	17173	17638	18079
Jiashan	11146	11650	12129	12628	13108	13636	14156	14697	15279	15863	16427	17035	17640	18241	18839
Yizheng	10554	11194	11842	12446	13103	13710	14323	14935	15498	16059	16627	17203	17773	18332	18904
Xiuzhou	11271	11811	12348	12914	13438	14001	14557	15092	15630	16165	16705	17285	17824	18372	18921
Huzhou	14643	14960	15325	15666	16007	16346	16697	17040	17384	17753	18116	18488	18840	19219	19602
Wujiang	18513	18737	18947	19142	19352	19557	19749	19942	20120	20295	20487	20658	20810	20972	21128
Tongxiang	12040	12643	13274	13929	14602	15278	16014	16688	17417	18105	18809	19538	20318	21080	21858
Tongzhou	19369	19553	19750	19952	20146	20343	20532	20771	20981	21186	21369	21545	21713	21869	22012
Xiucheng	13552	14158	14783	15412	16056	16680	17344	17951	18542	19185	19799	20394	20998	21603	22212
Changshu	20837	20993	21162	21334	21500	21701	21879	22053	22229	22413	22591	22771	22961	23154	23342
Zhangjiagang	25788	25788	25788	25788	25788	25788	25788	25788	25788	25788	25788	25788	25788	25788	25788
Liyang	11459	12294	13150	14004	14865	15805	16760	17723	18848	19955	21049	22206	23433	24692	25922
Zhenjiang	14099	14830	15596	16398	17217	18094	18999	19875	20754	21678	22610	23606	24563	25526	26490
Cixi	24863	25160	25474	25791	26105	26407	26700	26956	27194	27416	27653	27890	28106	28317	28489
Danyang	14280	15211	16160	17162	18152	19109	20134	21200	22314	23448	24609	25812	27020	28218	29462
Haining	17591	18803	20030	21217	22440	23629	24843	26091	27313	28563	29867	31111	32375	33613	34848
Yixing	27716	28768	29854	30944	32045	33128	34192	35199	36236	37347	38397	39485	40588	41668	42685
Jiangyin	33547	34369	35199	36020	36852	37721	38576	39446	40307	41211	42110	42971	43831	44679	45554
Kunshan	35091	36130	37253	38301	39353	40419	41508	42528	43583	44605	45610	46568	47525	48493	49503
Wuxi	65104	67194	69229	71241	73264	75230	77166	79025	80827	82622	84356	86038	87656	89170	90626
Changzhou	63966	66555	69073	71561	73967	76240	78470	80650	82797	84926	86959	88976	90919	92863	94750
Nanjing	61721	64273	66906	69521	72199	74884	77563	80206	82866	85532	88207	90878	93527	96120	98736
Suzhou	76040	78198	80264	82269	84299	86275	88161	90001	91800	93580	95254	96869	98486	100071	101594
Hangzhou	83707	86796	89755	92584	95411	98079	100667	103285	105845	108252	110650	112986	115358	117592	119874
Shanghai	271546	280397	289341	298222	306782	315258	323551	331904	339948	347930	355826	363493	371091	378627	385907

Table 17. Scenario 2: development corridors, plus big city growth urbanization prediction by city, 2016-2030.

City	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Zhoushan	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Wuxi	11.0837	11.1153	11.1452	11.1738	11.2018	11.2283	11.2537	11.2775	11.3001	11.3220	11.3428	11.3625	11.3812	11.3983	11.4145
Changzhou	11.0661	11.1058	11.1429	11.1783	11.2114	11.2416	11.2705	11.2979	11.3241	11.3495	11.3732	11.3961	11.4177	11.4389	11.4590
Shanghai	12.5119	12.5440	12.5754	12.6056	12.6339	12.6611	12.6871	12.7126	12.7365	12.7598	12.7822	12.8035	12.8242	12.8443	12.8634
Ningbo	7.7459	7.7836	7.8160	7.8501	7.8800	7.9106	7.9431	7.9694	8.0003	8.0288	8.0545	8.0790	8.1047	8.1283	8.1528
Suzhou	11.2390	11.2670	11.2931	11.3177	11.3421	11.3653	11.3869	11.4076	11.4274	11.4466	11.4643	11.4811	11.4977	11.5136	11.5287
Zhenjiang	9.5539	9.6044	9.6548	9.7049	9.7537	9.8033	9.8521	9.8972	9.9405	9.9841	10.0261	10.0693	10.1090	10.1475	10.1845
Nanjing	11.0304	11.0709	11.1110	11.1494	11.1872	11.2237	11.2588	11.2924	11.3250	11.3566	11.3874	11.4173	11.4460	11.4734	11.5002
Nantong	9.0469	9.0699	9.0926	9.1159	9.1368	9.1579	9.1760	9.1922	9.2054	9.2204	9.2321	9.2451	9.2569	9.2701	9.2821
Hangzhou	11.3351	11.3713	11.4048	11.4359	11.4659	11.4935	11.5196	11.5452	11.5697	11.5922	11.6141	11.6350	11.6558	11.6750	11.6942
Shaoxing	8.8777	8.9426	9.0034	9.0574	9.1080	9.1581	9.2028	9.2442	9.2835	9.3183	9.3516	9.3810	9.4094	9.4352	9.4587
Lishui	8.6993	8.7531	8.8042	8.8519	8.9003	8.9500	8.9978	9.0466	9.0919	9.1334	9.1737	9.2134	9.2498	9.2871	9.3238
Gaochun	7.9687	7.9773	7.9896	7.9993	8.0080	8.0180	8.0298	8.0414	8.0517	8.0643	8.0746	8.0849	8.0950	8.1086	8.1170
Jiangyin	10.4207	10.4449	10.4688	10.4918	10.5147	10.5380	10.5604	10.5827	10.6043	10.6265	10.6480	10.6683	10.6881	10.7073	10.7267
Yixing	10.2298	10.2670	10.3041	10.3399	10.3749	10.4081	10.4397	10.4688	10.4978	10.5280	10.5557	10.5837	10.6112	10.6375	10.6616
Liyang	9.3465	9.4169	9.4842	9.5471	9.6068	9.6681	9.7268	9.7826	9.8442	9.9012	9.9546	10.0081	10.0619	10.1142	10.1628
Jintan	8.6210	8.6505	8.6832	8.7128	8.7411	8.7694	8.7991	8.8286	8.8577	8.8904	8.9213	8.9513	8.9849	9.0147	9.0495
Changshu	9.9445	9.9519	9.9600	9.9681	9.9758	9.9851	9.9933	10.0012	10.0092	10.0174	10.0253	10.0332	10.0416	10.0499	10.0580
ngjiagang	10.1577	10.1577	10.1577	10.1577	10.1577	10.1577	10.1577	10.1577	10.1577	10.1577	10.1577	10.1577	10.1577	10.1577	10.1577
Kunshan	10.4657	10.4949	10.5255	10.5532	10.5803	10.6071	10.6336	10.6579	10.6824	10.7056	10.7279	10.7487	10.7690	10.7892	10.8098
Wujiang	9.8262	9.8383	9.8494	9.8596	9.8706	9.8811	9.8909	9.9006	9.9095	9.9181	9.9275	9.9359	9.9432	9.9509	9.9584
Taicang	9.4377	9.4630	9.4888	9.5145	9.5397	9.5663	9.5929	9.6164	9.6387	9.6610	9.6833	9.7043	9.7247	9.7464	9.7670
Rudong	7.0022	7.0022	7.0022	7.0022	7.0022	7.0022	7.0022	7.0022	7.0022	7.0022	7.0022	7.0022	7.0022	7.0022	7.0022
Qidong	9.2401	9.2401	9.2401	9.2401	9.2401	9.2401	9.2401	9.2401	9.2401	9.2401	9.2401	9.2401	9.2401	9.2401	9.2401
Rugao	8.6422	8.6422	8.6422	8.6422	8.6422	8.6422	8.6422	8.6422	8.6422	8.6422	8.6422	8.6422	8.6422	8.6422	8.6422
Tongzhou	9.8714	9.8809	9.8909	9.9011	9.9108	9.9205	9.9297	9.9413	9.9514	9.9611	9.9697	9.9779	9.9857	9.9928	9.9993
Haimen	9.2323	9.2323	9.2323	9.2323	9.2323	9.2323	9.2324	9.2324	9.2324	9.2324	9.2324	9.2325	9.2326	9.2329	9.2333
Yangzhou	9.2458	9.2949	9.3415	9.3829	9.4277	9.4716	9.5138	9.5524	9.5916	9.6271	9.6614	9.6952	9.7268	9.7582	9.7850
Yizheng	9.2643	9.3231	9.3794	9.4292	9.4806	9.5259	9.5696	9.6115	9.6485	9.6840	9.7188	9.7528	9.7854	9.8164	9.8471
Jiangdu	6.6796	6.6796	6.6796	6.6796	6.6796	6.6796	6.6796	6.6796	6.6796	6.6796	6.6796	6.6796	6.6796	6.6796	6.6796
Danyang	9.5666	9.6298	9.6903	9.7505	9.8065	9.8579	9.9102	9.9618	10.0130	10.0625	10.1109	10.1586	10.2043	10.2477	10.2909
Yangzhong	7.7324	7.7324	7.7324	7.7324	7.7324	7.7324	7.7324	7.7324	7.7324	7.7324	7.7324	7.7324	7.7324	7.7324	7.7324
Jurong	8.9123	8.9731	9.0340	9.0936	9.1471	9.2018	9.2548	9.3071	9.3572	9.4087	9.4581	9.5041	9.5495	9.5949	9.6382
Taizhou	7.2786	7.2786	7.2786	7.2786	7.2786	7.2786	7.2786	7.2786	7.2786	7.2786	7.2786	7.2786	7.2786	7.2786	7.2786
Jingjiang	8.7865	8.7866	8.7868	8.7868	8.7869	8.7871	8.7875	8.7881	8.7884	8.7887	8.7887	8.7892	8.7895	8.7898	8.7898
Taixing	8.8422	8.8422	8.8422	8.8422	8.8422	8.8422	8.8422	8.8422	8.8422	8.8422	8.8422	8.8422	8.8422	8.8422	8.8422
Jiangyan	5.2095	5.2095	5.2095	5.2095	5.2095	5.2095	5.2095	5.2095	5.2095	5.2095	5.2095	5.2095	5.2095	5.2095	5.2095
Fuyang	7.0031	7.0166	7.0246	7.0353	7.0432	7.0501	7.0544	7.0579	7.0639	7.0707	7.0741	7.0775	7.0800	7.0834	7.0884
Linan	7.8120	7.8188	7.8272	7.8332	7.8415	7.8482	7.8555	7.8633	7.8709	7.8785	7.8838	7.8898	7.8962	7.9017	7.9077
Yuyao	9.2368	9.2961	9.3524	9.4079	9.4571	9.5036	9.5459	9.5863	9.6236	9.6583	9.6896	9.7208	9.7511	9.7778	9.8025
Cixi	10.1211	10.1330	10.1454	10.1578	10.1699	10.1814	10.1924	10.2020	10.2108	10.2189	10.2275	10.2360	10.2437	10.2512	10.2573
Xiucheng	9.5143	9.5580	9.6012	9.6429	9.6838	9.7220	9.7610	9.7954	9.8278	9.8619	9.8934	9.9230	9.9522	9.9806	10.0084
Xiuzhou	9.3300	9.3768	9.4212	9.4661	9.5058	9.5469	9.5858	9.6219	9.6569	9.6906	9.7235	9.7576	9.7883	9.8186	9.8480
Jiashan	9.3188	9.3631	9.4034	9.4437	9.4810	9.5205	9.5579	9.5954	9.6342	9.6717	9.7067	9.7430	9.7779	9.8114	9.8437
Haiyan	8.3973	8.4876	8.5796	8.6623	8.7399	8.8173	8.8947	8.9669	9.0371	9.1049	9.1677	9.2276	9.2877	9.3434	9.3976
Haining	9.7751	9.8418	9.9050	9.9626	10.0186	10.0702	10.1203	10.1693	10.2151	10.2599	10.3045	10.3453	10.3851	10.4227	10.4588
Pinghu	9.0255	9.0687	9.1168	9.1640	9.2065	9.2509	9.2916	9.3349	9.3757	9.4150	9.4533	9.4921	9.5289	9.5655	9.6012
Tongxiang	9.3960	9.4449	9.4936	9.5417	9.5889	9.6342	9.6812	9.7224	9.7652	9.8039	9.8421	9.8801	9.9193	9.9561	9.9923
Huzhou	9.5917	9.6131	9.6372	9.6592	9.6808	9.7017	9.7230	9.7433	9.7633	9.7843	9.8046	9.8249	9.8437	9.8637	9.8834
Deqing	8.9678	9.0042	9.0416	9.0772	9.1111	9.1462	9.1775	9.2097	9.2404	9.2718	9.2991	9.3271	9.3553	9.3822	9.4083
Changxing	9.1269	9.1767	9.2252	9.2723	9.3178	9.3628	9.4061	9.4460	9.4827	9.5208	9.5580	9.5958	9.6321	9.6660	9.7003
Anji	8.5210	8.5289	8.5348	8.5417	8.5485	8.5551	8.5627	8.5686	8.5757	8.5826	8.5888	8.5977	8.6065	8.6150	8.6225
Shangyu	7.5601	7.5909	7.6158	7.6440	7.6658	7.6907	7.7107	7.7319	7.7536	7.7757	7.7948	7.8164	7.8324	7.8489	7.8633
Wuhu	3.0445	3.0445	3.0445	3.0445	3.0445	3.0445	3.0445	3.0445	3.0445	3.0445	3.0445	3.0445	3.0445	3.0445	3.0445
Xiangshan	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Dangtu	7.0834	7.0975	7.1058	7.1148	7.1317	7.1468	7.1608	7.1755	7.1884	7.1989	7.2064	7.2167	7.2255	7.2306	7.2371
Xuancheng	7.6912	7.6912	7.6912	7.6912	7.6912	7.6912	7.6912	7.6912	7.6912	7.6912	7.6912	7.6912	7.6912	7.6912	7.6912
Langxi	6.6606	6.6619	6.6631	6.6657	6.6682	6.6695	6.6708	6.6733	6.6758	6.6796	6.6834	6.6846	6.6859	6.6884	6.6908
Guangde	7.3759	7.3759	7.3759	7.3759	7.3759	7.3759	7.3759	7.3759	7.3759	7.3759	7.3759	7.3759	7.3759	7.3759	7.3759
Jingxian	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Jixi	5.0499	5.0499	5.0499	5.0499	5.0499	5.0499	5.0499	5.0499	5.0499	5.0499	5.0499	5.0499	5.0499	5.0499	5.0499
Jingde	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ningguo	7.3099	7.3099	7.3099	7.3099	7.3099	7.3099	7.3099	7.3099	7.3099	7.3099	7.3099	7.3099	7.3099	7.3099	7.3099

Table 18. Natural logarithms of scenario 2: development corridors, plus big city growth urbanization prediction by city, 2016-2030.

City	FID	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Zhoushan	0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Wuxi	1	0.8859	0.8861	0.8863	0.8864	0.8866	0.8868	0.8870	0.8871	0.8872	0.8873	0.8874	0.8875	0.8875	0.8874	0.8874
Changzhou	2	0.8844	0.8853	0.8861	0.8868	0.8874	0.8879	0.8883	0.8887	0.8891	0.8895	0.8898	0.8901	0.8903	0.8906	0.8908
Shanghai	3	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Ningbo	4	0.6191	0.6205	0.6215	0.6227	0.6237	0.6248	0.6261	0.6269	0.6281	0.6292	0.6301	0.6310	0.6320	0.6328	0.6338
Suzhou	5	0.8983	0.8982	0.8980	0.8978	0.8978	0.8977	0.8975	0.8973	0.8972	0.8971	0.8969	0.8967	0.8966	0.8964	0.8962
Zhenjiang	6	0.7636	0.7657	0.7678	0.7699	0.7720	0.7743	0.7765	0.7785	0.7805	0.7825	0.7844	0.7864	0.7883	0.7900	0.7917
Nanjing	7	0.8816	0.8826	0.8836	0.8845	0.8855	0.8865	0.8874	0.8883	0.8892	0.8900	0.8909	0.8917	0.8925	0.8933	0.8940
Nantong	8	0.7231	0.7231	0.7230	0.7232	0.7232	0.7233	0.7233	0.7231	0.7228	0.7226	0.7223	0.7221	0.7218	0.7217	0.7216
Hangzhou	9	0.9059	0.9065	0.9069	0.9072	0.9076	0.9078	0.9080	0.9082	0.9084	0.9085	0.9086	0.9087	0.9089	0.9090	0.9091
Shaoxing	10	0.7095	0.7129	0.7160	0.7185	0.7209	0.7233	0.7254	0.7272	0.7289	0.7303	0.7316	0.7327	0.7337	0.7346	0.7353
Lishui	11	0.6953	0.6978	0.7001	0.7022	0.7045	0.7069	0.7092	0.7116	0.7138	0.7158	0.7177	0.7196	0.7213	0.7231	0.7248
Gaochun	12	0.6369	0.6359	0.6353	0.6346	0.6339	0.6333	0.6329	0.6326	0.6322	0.6320	0.6317	0.6315	0.6312	0.6313	0.6310
Jiangyin	13	0.8329	0.8327	0.8325	0.8323	0.8323	0.8323	0.8324	0.8325	0.8326	0.8328	0.8330	0.8332	0.8334	0.8336	0.8339
Yixing	14	0.8176	0.8185	0.8194	0.8203	0.8212	0.8221	0.8229	0.8235	0.8242	0.8251	0.8258	0.8266	0.8274	0.8282	0.8288
Liyang	15	0.7470	0.7507	0.7542	0.7574	0.7604	0.7636	0.7667	0.7695	0.7729	0.7760	0.7788	0.7817	0.7846	0.7874	0.7901
Jintan	16	0.6890	0.6896	0.6905	0.6912	0.6919	0.6926	0.6935	0.6945	0.6955	0.6968	0.6979	0.6991	0.7006	0.7018	0.7035
Changshu	17	0.7948	0.7934	0.7920	0.7908	0.7896	0.7886	0.7877	0.7867	0.7859	0.7851	0.7843	0.7836	0.7830	0.7824	0.7819
ngjiagang	18	0.8118	0.8098	0.8077	0.8058	0.8040	0.8023	0.8006	0.7990	0.7975	0.7961	0.7947	0.7933	0.7921	0.7908	0.7897
Kunshan	19	0.8365	0.8366	0.8370	0.8372	0.8375	0.8378	0.8381	0.8384	0.8387	0.8390	0.8393	0.8395	0.8397	0.8400	0.8404
Wujiang	20	0.7854	0.7843	0.7832	0.7822	0.7813	0.7804	0.7796	0.7788	0.7780	0.7773	0.7767	0.7760	0.7753	0.7747	0.7742
Taicang	21	0.7543	0.7544	0.7546	0.7548	0.7551	0.7556	0.7561	0.7564	0.7568	0.7571	0.7576	0.7579	0.7583	0.7588	0.7593
Rudong	22	0.5596	0.5582	0.5568	0.5555	0.5542	0.5530	0.5519	0.5508	0.5498	0.5488	0.5478	0.5469	0.5460	0.5452	0.5443
Qidong	23	0.7385	0.7366	0.7348	0.7330	0.7314	0.7298	0.7283	0.7268	0.7255	0.7242	0.7229	0.7217	0.7205	0.7194	0.7183
Rugao	24	0.6907	0.6890	0.6872	0.6856	0.6841	0.6826	0.6812	0.6798	0.6785	0.6773	0.6761	0.6750	0.6739	0.6728	0.6718
Tongzhou	25	0.7890	0.7877	0.7865	0.7855	0.7845	0.7835	0.7827	0.7820	0.7813	0.7807	0.7800	0.7793	0.7787	0.7780	0.7774
Haimen	26	0.7379	0.7360	0.7342	0.7324	0.7308	0.7292	0.7277	0.7262	0.7249	0.7236	0.7223	0.7211	0.7199	0.7188	0.7178
Yangzhou	27	0.7390	0.7410	0.7428	0.7443	0.7462	0.7481	0.7499	0.7514	0.7531	0.7545	0.7558	0.7572	0.7585	0.7597	0.7607
Yizheng	28	0.7404	0.7432	0.7459	0.7480	0.7504	0.7524	0.7543	0.7561	0.7575	0.7590	0.7603	0.7617	0.7630	0.7643	0.7655
Jiangdu	29	0.5339	0.5325	0.5312	0.5299	0.5287	0.5276	0.5265	0.5254	0.5244	0.5235	0.5226	0.5217	0.5209	0.5200	0.5193
Danyang	30	0.7646	0.7677	0.7706	0.7735	0.7762	0.7786	0.7811	0.7836	0.7862	0.7886	0.7910	0.7934	0.7957	0.7978	0.8000
Yangzhong	31	0.6180	0.6164	0.6149	0.6134	0.6120	0.6107	0.6095	0.6082	0.6071	0.6060	0.6049	0.6039	0.6030	0.6020	0.6011
Jurong	32	0.7123	0.7153	0.7184	0.7214	0.7240	0.7268	0.7295	0.7321	0.7347	0.7374	0.7399	0.7423	0.7446	0.7470	0.7493
Taizhou	33	0.5817	0.5802	0.5788	0.5774	0.5761	0.5749	0.5737	0.5726	0.5715	0.5704	0.5694	0.5685	0.5676	0.5667	0.5658
Jingjiang	34	0.7022	0.7005	0.6987	0.6971	0.6955	0.6940	0.6926	0.6913	0.6900	0.6888	0.6876	0.6865	0.6854	0.6843	0.6833
Taixing	35	0.7067	0.7049	0.7031	0.7014	0.6999	0.6984	0.6969	0.6955	0.6942	0.6930	0.6918	0.6906	0.6895	0.6884	0.6874
Jiangyan	36	0.4164	0.4153	0.4143	0.4133	0.4123	0.4115	0.4106	0.4098	0.4090	0.4083	0.4076	0.4069	0.4062	0.4056	0.4050
Fuyang	37	0.5597	0.5594	0.5586	0.5581	0.5575	0.5568	0.5560	0.5552	0.5546	0.5541	0.5534	0.5528	0.5521	0.5515	0.5511
Linan	38	0.6244	0.6233	0.6224	0.6214	0.6207	0.6199	0.6192	0.6185	0.6180	0.6175	0.6168	0.6162	0.6157	0.6152	0.6147
Yuyao	39	0.7382	0.7411	0.7437	0.7463	0.7486	0.7506	0.7524	0.7541	0.7556	0.7569	0.7581	0.7592	0.7604	0.7613	0.7620
Cixi	40	0.8089	0.8078	0.8068	0.8058	0.8050	0.8041	0.8034	0.8025	0.8017	0.8009	0.8001	0.7995	0.7988	0.7981	0.7974
Xiucheng	41	0.7604	0.7620	0.7635	0.7650	0.7665	0.7679	0.7694	0.7705	0.7716	0.7729	0.7740	0.7750	0.7760	0.7770	0.7781
Xiuzhou	42	0.7457	0.7475	0.7492	0.7509	0.7524	0.7540	0.7556	0.7569	0.7582	0.7595	0.7607	0.7621	0.7633	0.7644	0.7656
Jiashan	43	0.7448	0.7464	0.7478	0.7492	0.7504	0.7519	0.7534	0.7548	0.7564	0.7580	0.7594	0.7610	0.7625	0.7639	0.7653
Haiyan	44	0.6711	0.6766	0.6823	0.6872	0.6918	0.6964	0.7011	0.7054	0.7095	0.7136	0.7172	0.7207	0.7242	0.7274	0.7306
Haining	45	0.7813	0.7846	0.7877	0.7903	0.7930	0.7954	0.7977	0.7999	0.8020	0.8041	0.8062	0.8080	0.8098	0.8115	0.8131
Pinghu	46	0.7214	0.7230	0.7250	0.7270	0.7287	0.7307	0.7324	0.7343	0.7361	0.7379	0.7396	0.7414	0.7430	0.7447	0.7464
Tongxiang	47	0.7510	0.7529	0.7549	0.7569	0.7590	0.7609	0.7631	0.7648	0.7667	0.7683	0.7700	0.7717	0.7735	0.7751	0.7768
Huzhou	48	0.7666	0.7664	0.7664	0.7663	0.7663	0.7663	0.7664	0.7664	0.7666	0.7668	0.7670	0.7674	0.7676	0.7679	0.7683
Deqing	49	0.7167	0.7178	0.7190	0.7201	0.7212	0.7224	0.7234	0.7245	0.7255	0.7266	0.7275	0.7285	0.7295	0.7305	0.7314
Changxing	50	0.7295	0.7316	0.7336	0.7356	0.7375	0.7395	0.7414	0.7430	0.7445	0.7462	0.7478	0.7495	0.7511	0.7526	0.7541
Anji	51	0.6810	0.6799	0.6787	0.6776	0.6766	0.6757	0.6749	0.6740	0.6733	0.6726	0.6719	0.6715	0.6711	0.6707	0.6703
Shangyu	52	0.6042	0.6051	0.6056	0.6064	0.6068	0.6074	0.6078	0.6082	0.6088	0.6094	0.6098	0.6105	0.6108	0.6111	0.6113
Wuhu	53	0.2433	0.2427	0.2421	0.2415	0.2410	0.2405	0.2400	0.2395	0.2390	0.2386	0.2382	0.2378	0.2374	0.2370	0.2367
Xiangshan	54	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Dangtu	55	0.5661	0.5658	0.5651	0.5644	0.5645	0.5645	0.5644	0.5644	0.5644	0.5642	0.5638	0.5637	0.5634	0.5629	0.5626
Xuancheng	56	0.6147	0.6131	0.6116	0.6101	0.6088	0.6075	0.6062	0.6050	0.6039	0.6028	0.6017	0.6007	0.5997	0.5988	0.5979
Langxi	57	0.5323	0.5311	0.5299	0.5288	0.5278	0.5268	0.5258	0.5249	0.5241	0.5235	0.5229	0.5221	0.5213	0.5207	0.5201
Guangde	58	0.5895	0.5880	0.5865	0.5851	0.5838	0.5826	0.5814	0.5802	0.5791	0.5781	0.5770	0.5761	0.5752	0.5743	0.5734
Jingxian	59	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Jixi	60	0.4036	0.4026	0.4016	0.4006	0.3997	0.3988	0.3980	0.3972	0.3965	0.3958	0.3951	0.3944	0.3938	0.3932	0.3926
Jingde	61	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ningguo	62	0.5842	0.5827	0.5813	0.5799	0.5786	0.5773	0.5762	0.5750	0.5739	0.5729	0.5719	0.5709	0.5700	0.5691	0.5683

Table 19. Normalization of scenario 2: development corridors, plus big city growth urbanization prediction by city, 2016-2030.

iii. Scenario 3: ecological system concerns, plus development corridors

Yet, again, the results of city-level urban growth prediction were reproduced here. Figures 90, 91, and 92 show the urban growth prediction outcomes from scenario 3: ecological system concerns, plus development corridors by city from 2016 to 2030. The Scenario Cellular Automata model was used, once again, to predict from 2011 to 2030 and data from 2011 to 2015 were not presented here. Table 16 shows scenario 3: ecological system concerns, plus development corridor urban growth prediction by city, Table 17 shows the urban growth prediction data processed by natural logarithms, and Table 18 shows the normalization of the urban growth prediction.

In much the same way, as other scenario projections, during the prediction period, the urbanization area, represented by grid pixels, of each city grew at different rates with much the same outcomes as described earlier.

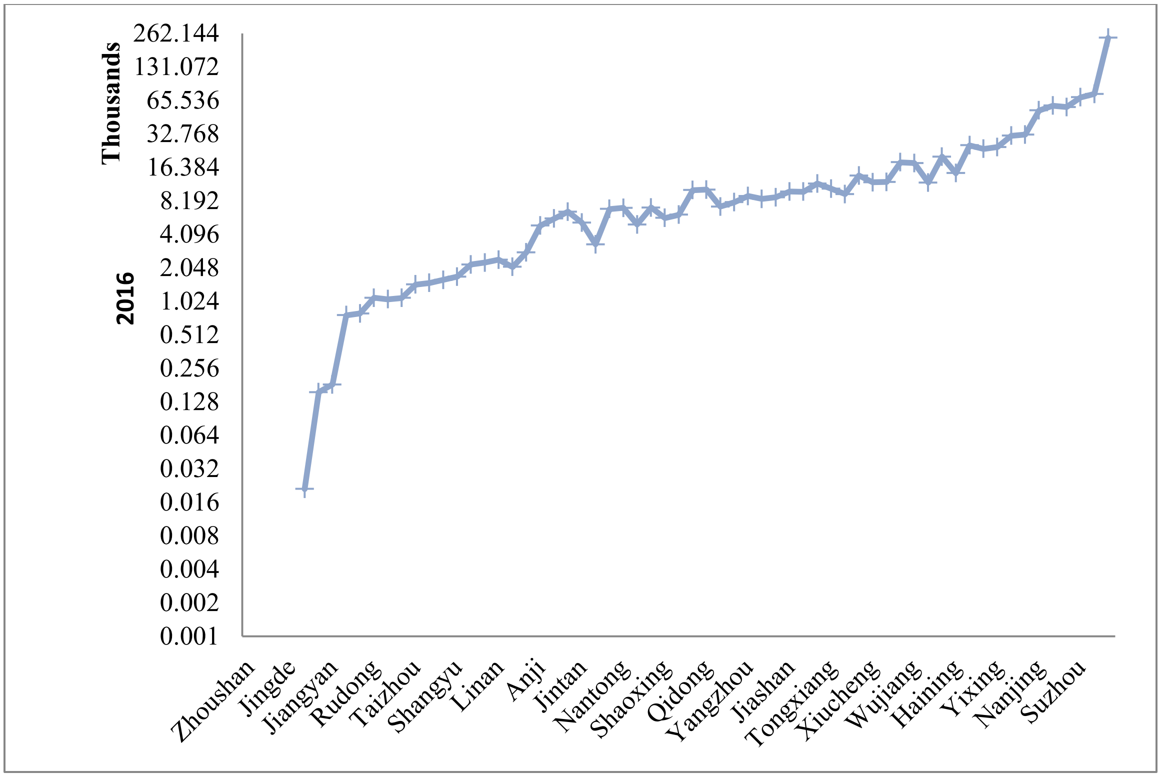


Figure 90. Logarithmic ranking of cities and towns, 2016, scenario 3: ecological system concerns, plus development corridors.

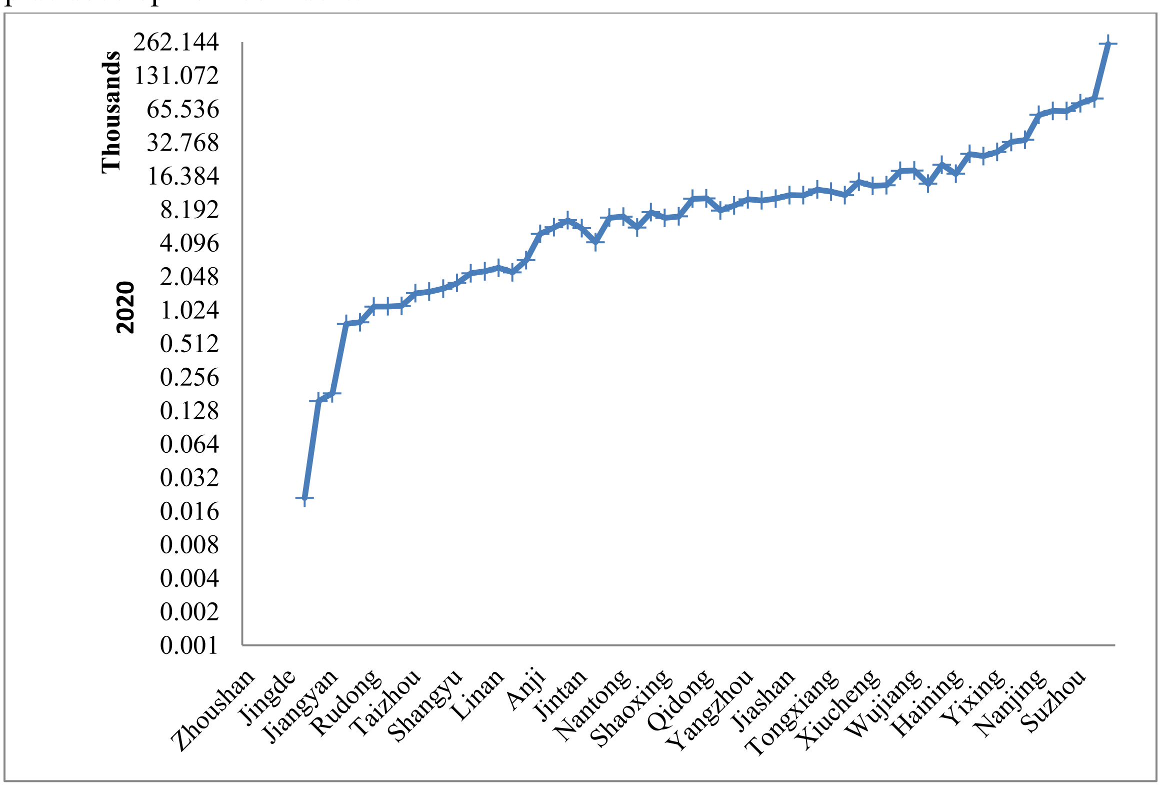


Figure 91. Logarithmic ranking of cities and towns, 2020, scenario 3: ecological system concerns, plus development corridors.

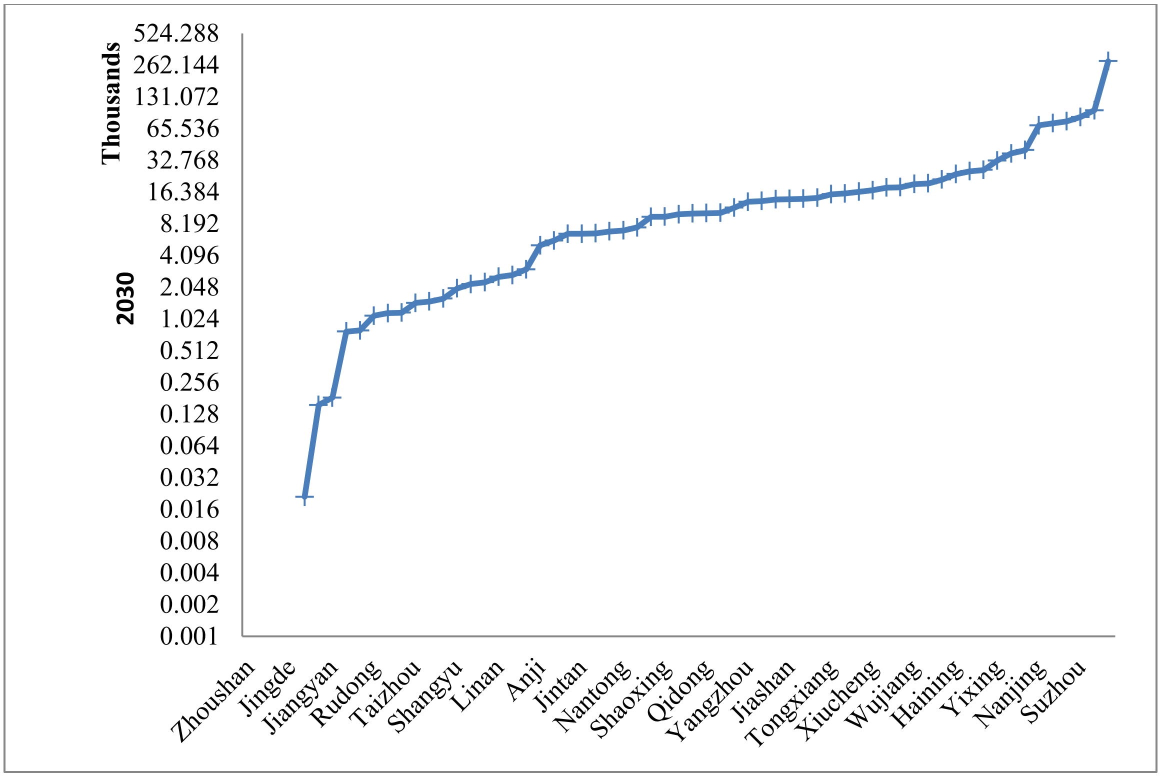


Figure 92. Logarithmic ranking of cities and towns, 2030, scenario 3: ecological system concerns, plus development corridors.

City	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Zhoushan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Xiangshan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Jingxian	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Jingde	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wuhu	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21
Jixi	156	156	156	156	156	156	156	156	156	156	156	156	156	156	156
Jiangyan	183	183	183	183	183	183	183	183	183	183	183	183	183	183	183
Langxi	767	768	768	768	768	769	770	772	774	774	774	775	776	776	776
Jiangdu	796	796	796	796	796	796	796	796	796	796	796	796	796	796	796
Rudong	1099	1099	1099	1099	1099	1099	1099	1099	1099	1099	1099	1099	1099	1099	1099
Fuyang	1066	1075	1082	1091	1103	1111	1117	1128	1132	1139	1142	1147	1154	1156	1160
Dangtu	1097	1101	1106	1110	1114	1121	1126	1135	1140	1149	1151	1157	1162	1168	1174
Taizhou	1449	1449	1449	1449	1449	1449	1449	1449	1449	1449	1449	1449	1449	1449	1449
Ningguo	1495	1495	1495	1495	1495	1495	1495	1495	1495	1495	1495	1495	1495	1495	1495
Guangde	1595	1595	1595	1595	1595	1595	1595	1595	1595	1595	1595	1595	1595	1595	1595
Shangyu	1701	1729	1754	1773	1788	1810	1835	1860	1884	1910	1926	1939	1957	1978	1996
Xuancheng	2189	2189	2189	2189	2189	2189	2189	2189	2189	2189	2189	2189	2189	2189	2189
Yangzhong	2281	2281	2281	2281	2281	2281	2281	2281	2281	2281	2281	2281	2281	2281	2281
Linan	2418	2427	2435	2445	2454	2472	2481	2498	2507	2520	2531	2541	2547	2559	2566
Ningbo	2084	2117	2163	2200	2236	2275	2316	2363	2408	2449	2485	2536	2573	2614	2662
Gaochun	2816	2830	2844	2859	2872	2892	2905	2924	2936	2951	2962	2975	2988	3005	3020
Anji	4900	4916	4927	4937	4950	4961	4976	4995	5013	5028	5039	5053	5073	5090	5106
Rugao	5666	5666	5666	5666	5666	5666	5666	5666	5666	5666	5666	5666	5666	5666	5666
Jingjiang	6541	6541	6541	6543	6545	6546	6547	6547	6547	6549	6551	6553	6553	6556	6558
Jintan	5220	5299	5378	5459	5544	5641	5717	5799	5896	6005	6108	6218	6332	6444	6572
Haiyan	3320	3527	3731	3963	4157	4400	4620	4855	5079	5321	5554	5824	6078	6365	6643
Taixing	6920	6920	6920	6920	6920	6920	6920	6920	6920	6920	6920	6920	6920	6920	6920
Nantong	7064	7064	7064	7064	7064	7064	7064	7064	7064	7064	7064	7064	7064	7064	7064
Lishui	5007	5175	5346	5494	5652	5814	6005	6197	6355	6557	6756	6941	7138	7355	7561
Deqing	7115	7268	7430	7578	7735	7906	8056	8213	8415	8583	8771	8961	9145	9339	9529
Shaoxing	5745	6014	6306	6588	6878	7148	7450	7739	8013	8264	8539	8805	9055	9293	9556
Jurong	6127	6361	6593	6840	7102	7391	7678	7949	8213	8498	8794	9094	9421	9736	10053
Haimen	10222	10222	10222	10222	10222	10222	10222	10222	10222	10222	10222	10222	10222	10222	10222
Qidong	10302	10302	10302	10302	10302	10302	10302	10302	10302	10302	10302	10302	10302	10302	10302
Pinghu	7252	7437	7608	7811	8029	8244	8443	8651	8889	9121	9365	9620	9887	10118	10379
Changxing	7933	8168	8374	8607	8871	9113	9377	9637	9905	10188	10445	10711	11008	11308	11597
Yangzhou	9047	9302	9567	9823	10098	10371	10652	10944	11260	11569	11896	12203	12533	12876	13216
Yuyao	8506	8854	9181	9533	9883	10231	10586	10966	11307	11671	12028	12396	12757	13110	13430
Yizheng	8795	9159	9490	9864	10232	10577	10934	11299	11645	12045	12401	12778	13163	13538	13901
Jiashan	9899	10188	10478	10751	11029	11295	11553	11867	12170	12477	12775	13067	13372	13713	14030
Xiuzhou	9870	10148	10417	10689	10973	11244	11549	11853	12165	12491	12816	13148	13482	13784	14108
Taicang	11678	11840	12008	12176	12361	12548	12734	12939	13146	13350	13554	13776	13995	14211	14429
Tongxiang	10518	10850	11159	11505	11850	12202	12567	12945	13313	13670	14027	14397	14801	15166	15563
Liyang	9401	9755	10183	10600	11017	11429	11849	12274	12768	13270	13748	14268	14772	15315	15831
Huzhou	13809	13958	14140	14324	14510	14689	14869	15049	15258	15449	15651	15858	16063	16255	16440
Xiucheng	12009	12328	12659	12996	13331	13678	14035	14394	14749	15130	15517	15902	16265	16623	17003
Zhenjiang	12084	12440	12793	13174	13528	13920	14333	14735	15163	15624	16096	16580	17063	17541	18015
Tongzhou	18186	18186	18186	18186	18186	18186	18186	18186	18186	18186	18186	18186	18186	18186	18186
Wujiang	17888	18003	18126	18227	18340	18452	18570	18691	18815	18933	19039	19162	19277	19379	19493
Danyang	11926	12443	12921	13406	13922	14416	14953	15501	16055	16667	17275	17887	18469	19105	19726
Changshu	20409	20471	20535	20603	20676	20756	20829	20908	20981	21068	21141	21217	21294	21381	21458
Haining	14521	15148	15791	16433	17135	17832	18513	19217	19909	20612	21326	22013	22718	23441	24162
Zhangjiagang	25788	25788	25788	25788	25788	25788	25788	25788	25788	25788	25788	25788	25788	25788	25788
Cixi	23974	24172	24358	24544	24742	24928	25119	25323	25504	25680	25877	26039	26197	26342	26478
Yixing	24863	25383	25886	26405	26957	27509	28038	28584	29153	29716	30274	30847	31401	31945	32547
Jiangyin	31506	31920	32327	32727	33125	33560	34015	34461	34942	35441	35929	36413	36913	37429	37920
Kunshan	32240	32785	33335	33894	34497	35069	35679	36292	36956	37572	38217	38873	39527	40180	40843
Nanjing	53122	54278	55423	56547	57792	58983	60197	61457	62647	63890	65111	66412	67678	68931	70266
Wuxi	58699	59748	60810	61823	62875	63952	65016	66082	67170	68246	69304	70353	71371	72428	73456
Changzhou	56933	58363	59803	61218	62669	64135	65546	67000	68426	69861	71250	72678	74036	75382	76740
Suzhou	69616	70671	71672	72733	73788	74868	75967	77053	78090	79141	80185	81233	82262	83286	84325
Hangzhou	74683	76327	78017	79664	81299	82944	84646	86327	87974	89629	91195	92819	94385	95907	97416
Shanghai	238582	241916	245285	248604	252093	255461	258843	262277	265657	269021	272309	275552	278757	282006	285173

Table 20. Scenario 3: ecological system concerns, plus development corridors urban growth prediction by city, 2016-2030.

City	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Zhoushan	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Wuxi	10.9802	10.9979	11.0155	11.0320	11.0489	11.0659	11.0824	11.0987	11.1150	11.1309	11.1463	11.1613	11.1756	11.1903	11.2044
Changzhou	10.9496	10.9744	10.9988	11.0222	11.0456	11.0687	11.0905	11.1124	11.1335	11.1543	11.1740	11.1938	11.2123	11.2303	11.2482
Shanghai	12.3825	12.3963	12.4102	12.4236	12.4376	12.4508	12.4640	12.4772	12.4900	12.5025	12.5147	12.5265	12.5381	12.5497	12.5609
Ningbo	7.6420	7.6578	7.6793	7.6962	7.7124	7.7297	7.7476	7.7677	7.7866	7.8034	7.8180	7.8383	7.8528	7.8686	7.8868
Suzhou	11.1507	11.1658	11.1799	11.1946	11.2090	11.2235	11.2381	11.2522	11.2656	11.2790	11.2921	11.3051	11.3177	11.3300	11.3424
Zhenjiang	9.3996	9.4287	9.4567	9.4860	9.5125	9.5411	9.5703	9.5980	9.6266	9.6566	9.6863	9.7160	9.7447	9.7723	9.7990
Nanjing	10.8803	10.9019	10.9227	10.9428	10.9646	10.9850	11.0054	11.0261	11.0453	11.0649	11.0838	11.1036	11.1225	11.1409	11.1600
Nantong	8.8628	8.8628	8.8628	8.8628	8.8628	8.8628	8.8628	8.8628	8.8628	8.8628	8.8628	8.8628	8.8628	8.8628	8.8628
Hangzhou	11.2210	11.2428	11.2647	11.2856	11.3059	11.3259	11.3462	11.3659	11.3848	11.4034	11.4208	11.4384	11.4551	11.4711	11.4867
Shaoxing	8.6561	8.7018	8.7493	8.7930	8.8361	8.8746	8.9160	8.9540	8.9888	9.0197	9.0524	9.0831	9.1111	9.1370	9.1649
Lishui	8.5186	8.5516	8.5841	8.6114	8.6398	8.6680	8.7003	8.7318	8.7570	8.7883	8.8182	8.8452	8.8732	8.9031	8.9308
Gaochun	7.9431	7.9480	7.9530	7.9582	7.9628	7.9697	7.9742	7.9807	7.9848	7.9899	7.9936	7.9980	8.0024	8.0080	8.0130
Jiangyin	10.3579	10.3710	10.3837	10.3960	10.4080	10.4211	10.4346	10.4476	10.4614	10.4756	10.4893	10.5027	10.5163	10.5302	10.5432
Yixing	10.1211	10.1418	10.1615	10.1813	10.2020	10.2223	10.2413	10.2606	10.2803	10.2994	10.3180	10.3368	10.3546	10.3718	10.3904
Liyang	9.1486	9.1855	9.2285	9.2686	9.3072	9.3439	9.3800	9.4152	9.4547	9.4933	9.5286	9.5658	9.6005	9.6366	9.6697
Jintan	8.5603	8.5753	8.5901	8.6050	8.6205	8.6378	8.6512	8.6654	8.6820	8.7003	8.7174	8.7352	8.7534	8.7709	8.7906
Changshu	9.9237	9.9268	9.9299	9.9332	9.9367	9.9406	9.9441	9.9479	9.9514	9.9555	9.9590	9.9626	9.9662	9.9703	9.9739
Zhangjiagang	10.1577	10.1577	10.1577	10.1577	10.1577	10.1577	10.1577	10.1577	10.1577	10.1577	10.1577	10.1577	10.1577	10.1577	10.1577
Kunshan	10.3810	10.3977	10.4144	10.4310	10.4486	10.4651	10.4823	10.4994	10.5175	10.5340	10.5510	10.5681	10.5847	10.6011	10.6175
Wujiang	9.7919	9.7983	9.8051	9.8107	9.8168	9.8229	9.8293	9.8358	9.8424	9.8487	9.8542	9.8607	9.8667	9.8719	9.8778
Taicang	9.3655	9.3792	9.3933	9.4072	9.4223	9.4373	9.4520	9.4680	9.4839	9.4993	9.5144	9.5307	9.5465	9.5618	9.5770
Rudong	7.0022	7.0022	7.0022	7.0022	7.0022	7.0022	7.0022	7.0022	7.0022	7.0022	7.0022	7.0022	7.0022	7.0022	7.0022
Qidong	9.2401	9.2401	9.2401	9.2401	9.2401	9.2401	9.2401	9.2401	9.2401	9.2401	9.2401	9.2401	9.2401	9.2401	9.2401
Rugao	8.6422	8.6422	8.6422	8.6422	8.6422	8.6422	8.6422	8.6422	8.6422	8.6422	8.6422	8.6422	8.6422	8.6422	8.6422
Tongzhou	9.8084	9.8084	9.8084	9.8084	9.8084	9.8084	9.8084	9.8084	9.8084	9.8084	9.8084	9.8084	9.8084	9.8084	9.8084
Haimen	9.2323	9.2323	9.2323	9.2323	9.2323	9.2323	9.2323	9.2323	9.2323	9.2323	9.2323	9.2323	9.2323	9.2323	9.2323
Yangzhou	9.1102	9.1380	9.1661	9.1925	9.2201	9.2468	9.2735	9.3005	9.3290	9.3561	9.3840	9.4094	9.4361	9.4631	9.4892
Yizheng	9.0819	9.1225	9.1580	9.1966	9.2333	9.2664	9.2996	9.3325	9.3626	9.3964	9.4255	9.4555	9.4852	9.5133	9.5397
Jiangdu	6.6796	6.6796	6.6796	6.6796	6.6796	6.6796	6.6796	6.6796	6.6796	6.6796	6.6796	6.6796	6.6796	6.6796	6.6796
Danyang	9.3865	9.4289	9.4666	9.5035	9.5412	9.5761	9.6127	9.6487	9.6838	9.7212	9.7570	9.7918	9.8238	9.8577	9.8897
Yangzhong	7.7324	7.7324	7.7324	7.7324	7.7324	7.7324	7.7324	7.7324	7.7324	7.7324	7.7324	7.7324	7.7324	7.7324	7.7324
Jurong	8.7205	8.7579	8.7938	8.8305	8.8681	8.9080	8.9461	8.9808	9.0135	9.0476	9.0818	9.1154	9.1507	9.1836	9.2156
Taizhou	7.2786	7.2786	7.2786	7.2786	7.2786	7.2786	7.2786	7.2786	7.2786	7.2786	7.2786	7.2786	7.2786	7.2786	7.2786
Jingjiang	8.7858	8.7858	8.7858	8.7862	8.7865	8.7866	8.7868	8.7868	8.7868	8.7871	8.7874	8.7877	8.7877	8.7881	8.7884
Taixing	8.8422	8.8422	8.8422	8.8422	8.8422	8.8422	8.8422	8.8422	8.8422	8.8422	8.8422	8.8422	8.8422	8.8422	8.8422
Jiangyan	5.2095	5.2095	5.2095	5.2095	5.2095	5.2095	5.2095	5.2095	5.2095	5.2095	5.2095	5.2095	5.2095	5.2095	5.2095
Fuyang	6.9717	6.9801	6.9866	6.9948	7.0058	7.0130	7.0184	7.0282	7.0317	7.0379	7.0405	7.0449	7.0510	7.0527	7.0562
Linan	7.7907	7.7944	7.7977	7.8018	7.8055	7.8128	7.8164	7.8232	7.8268	7.8320	7.8364	7.8403	7.8427	7.8474	7.8501
Yuyao	9.0485	9.0886	9.1249	9.1625	9.1986	9.2332	9.2673	9.3026	9.3332	9.3649	9.3950	9.4251	9.4538	9.4811	9.5052
Cixi	10.0847	10.0930	10.1006	10.1082	10.1163	10.1237	10.1314	10.1395	10.1466	10.1535	10.1611	10.1674	10.1734	10.1789	10.1841
Xiucheng	9.3934	9.4196	9.4461	9.4724	9.4978	9.5235	9.5493	9.5746	9.5989	9.6244	9.6497	9.6742	9.6968	9.7185	9.7411
Xiuzhou	9.1973	9.2250	9.2512	9.2770	9.3032	9.3276	9.3544	9.3803	9.4063	9.4328	9.4584	9.4840	9.5091	9.5313	9.5545
Jiashan	9.2002	9.2290	9.2570	9.2828	9.3083	9.3321	9.3547	9.3815	9.4067	9.4316	9.4552	9.4778	9.5009	9.5261	9.5490
Haiyan	8.1077	8.1682	8.2244	8.2848	8.3325	8.3894	8.4381	8.4878	8.5329	8.5794	8.6223	8.6697	8.7124	8.7586	8.8013
Haining	9.5834	9.6256	9.6672	9.7070	9.7489	9.7887	9.8262	9.8636	9.8989	9.9336	9.9677	9.9994	10.0309	10.0622	10.0925
Pinghu	8.8890	8.9142	8.9370	8.9633	8.9908	9.0172	9.0411	9.0654	9.0926	9.1183	9.1447	9.1716	9.1990	9.2221	9.2475
Tongxiang	9.2608	9.2919	9.3200	9.3505	9.3801	9.4094	9.4388	9.4685	9.4965	9.5230	9.5487	9.5748	9.6025	9.6268	9.6527
Huzhou	9.5331	9.5438	9.5568	9.5697	9.5826	9.5949	9.6070	9.6191	9.6329	9.6453	9.6583	9.6714	9.6843	9.6962	9.7075
Deqing	8.8700	8.8912	8.9133	8.9330	8.9535	8.9754	8.9942	9.0135	9.0378	9.0575	9.0792	9.1006	9.1210	9.1420	9.1621
Changxing	8.9788	9.0080	9.0329	9.0603	9.0905	9.1175	9.1460	9.1734	9.2008	9.2290	9.2539	9.2790	9.3064	9.3333	9.3585
Anji	8.4970	8.5003	8.5025	8.5045	8.5071	8.5094	8.5124	8.5162	8.5198	8.5228	8.5250	8.5277	8.5317	8.5350	8.5382
Shangyu	7.4390	7.4553	7.4697	7.4804	7.4889	7.5011	7.5148	7.5283	7.5412	7.5549	7.5632	7.5699	7.5792	7.5898	7.5989
Wuhu	3.0445	3.0445	3.0445	3.0445	3.0445	3.0445	3.0445	3.0445	3.0445	3.0445	3.0445	3.0445	3.0445	3.0445	3.0445
Xiangshan	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Dangtu	7.0003	7.0040	7.0085	7.0121	7.0157	7.0220	7.0264	7.0344	7.0388	7.0466	7.0484	7.0536	7.0579	7.0630	7.0682
Xuancheng	7.6912	7.6912	7.6912	7.6912	7.6912	7.6912	7.6912	7.6912	7.6912	7.6912	7.6912	7.6912	7.6912	7.6912	7.6912
Langxi	6.6425	6.6438	6.6438	6.6438	6.6438	6.6451	6.6464	6.6490	6.6516	6.6516	6.6516	6.6529	6.6542	6.6542	6.6542
Guangde	7.3746	7.3746	7.3746	7.3746	7.3746	7.3746	7.3746	7.3746	7.3746	7.3746	7.3746	7.3746	7.3746	7.3746	7.3746
Jingxian	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Jixi	5.0499	5.0499	5.0499	5.0499	5.0499	5.0499	5.0499	5.0499	5.0499	5.0499	5.0499	5.0499	5.0499	5.0499	5.0499
Jingde	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ningguo	7.3099	7.3099	7.3099	7.3099	7.3099	7.3099	7.3099	7.3099	7.3099	7.3099	7.3099	7.3099	7.3099	7.3099	7.3099

Table 21. Natural logarithmic of scenario 3: ecological system concerns, plus development corridors urban growth prediction by city, 2016-2030.

City	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Zhoushan	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Wuxi	0.8868	0.8872	0.8876	0.8880	0.8884	0.8888	0.8892	0.8895	0.8899	0.8903	0.8907	0.8910	0.8913	0.8917	0.8920
Changzhou	0.8843	0.8853	0.8863	0.8872	0.8881	0.8890	0.8898	0.8906	0.8914	0.8922	0.8929	0.8936	0.8943	0.8949	0.8955
Shanghai	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Ningbo	0.6172	0.6177	0.6188	0.6195	0.6201	0.6208	0.6216	0.6226	0.6234	0.6241	0.6247	0.6257	0.6263	0.6270	0.6279
Suzhou	0.9005	0.9007	0.9009	0.9011	0.9012	0.9014	0.9016	0.9018	0.9020	0.9021	0.9023	0.9025	0.9027	0.9028	0.9030
Zhenjiang	0.7591	0.7606	0.7620	0.7635	0.7648	0.7663	0.7678	0.7692	0.7707	0.7724	0.7740	0.7756	0.7772	0.7787	0.7801
Nanjing	0.8787	0.8794	0.8801	0.8808	0.8816	0.8823	0.8830	0.8837	0.8843	0.8850	0.8857	0.8864	0.8871	0.8877	0.8885
Nantong	0.7158	0.7149	0.7142	0.7134	0.7126	0.7118	0.7111	0.7103	0.7096	0.7089	0.7082	0.7075	0.7069	0.7062	0.7056
Hangzhou	0.9062	0.9069	0.9077	0.9084	0.9090	0.9097	0.9103	0.9109	0.9115	0.9121	0.9126	0.9131	0.9136	0.9141	0.9145
Shaoxing	0.6991	0.7020	0.7050	0.7078	0.7104	0.7128	0.7153	0.7176	0.7197	0.7214	0.7233	0.7251	0.7267	0.7281	0.7296
Lishui	0.6880	0.6898	0.6917	0.6931	0.6947	0.6962	0.6980	0.6998	0.7011	0.7029	0.7046	0.7061	0.7077	0.7094	0.7110
Gaochun	0.6415	0.6412	0.6408	0.6406	0.6402	0.6401	0.6398	0.6396	0.6393	0.6391	0.6387	0.6385	0.6382	0.6381	0.6379
Jiangyin	0.8365	0.8366	0.8367	0.8368	0.8368	0.8370	0.8372	0.8373	0.8376	0.8379	0.8382	0.8384	0.8387	0.8391	0.8394
Yixing	0.8174	0.8181	0.8188	0.8195	0.8203	0.8210	0.8217	0.8224	0.8231	0.8238	0.8245	0.8252	0.8259	0.8265	0.8272
Liyang	0.7388	0.7410	0.7436	0.7460	0.7483	0.7505	0.7526	0.7546	0.7570	0.7593	0.7614	0.7636	0.7657	0.7679	0.7698
Jintan	0.6913	0.6918	0.6922	0.6926	0.6931	0.6938	0.6941	0.6945	0.6951	0.6959	0.6966	0.6973	0.6981	0.6989	0.6998
Changshu	0.8014	0.8008	0.8001	0.7995	0.7989	0.7984	0.7978	0.7973	0.7967	0.7963	0.7958	0.7953	0.7949	0.7945	0.7940
ngjiagang	0.8203	0.8194	0.8185	0.8176	0.8167	0.8158	0.8150	0.8141	0.8133	0.8124	0.8117	0.8109	0.8101	0.8094	0.8087
Kunshan	0.8384	0.8388	0.8392	0.8396	0.8401	0.8405	0.8410	0.8415	0.8421	0.8425	0.8431	0.8437	0.8442	0.8447	0.8453
Wujiang	0.7908	0.7904	0.7901	0.7897	0.7893	0.7889	0.7886	0.7883	0.7880	0.7877	0.7874	0.7872	0.7869	0.7866	0.7864
Taicang	0.7563	0.7566	0.7569	0.7572	0.7576	0.7580	0.7583	0.7588	0.7593	0.7598	0.7603	0.7608	0.7614	0.7619	0.7624
Rudong	0.5655	0.5649	0.5642	0.5636	0.5630	0.5624	0.5618	0.5612	0.5606	0.5601	0.5595	0.5590	0.5585	0.5580	0.5575
Qidong	0.7462	0.7454	0.7446	0.7438	0.7429	0.7421	0.7413	0.7406	0.7398	0.7391	0.7383	0.7376	0.7370	0.7363	0.7356
Rugao	0.6979	0.6972	0.6964	0.6956	0.6949	0.6941	0.6934	0.6926	0.6919	0.6912	0.6906	0.6899	0.6893	0.6886	0.6880
Tongzhou	0.7921	0.7912	0.7904	0.7895	0.7886	0.7878	0.7869	0.7861	0.7853	0.7845	0.7838	0.7830	0.7823	0.7816	0.7809
Haimen	0.7456	0.7448	0.7439	0.7431	0.7423	0.7415	0.7407	0.7399	0.7392	0.7384	0.7377	0.7370	0.7363	0.7357	0.7350
Yangzhou	0.7357	0.7372	0.7386	0.7399	0.7413	0.7427	0.7440	0.7454	0.7469	0.7483	0.7498	0.7512	0.7526	0.7541	0.7555
Yizheng	0.7335	0.7359	0.7379	0.7403	0.7424	0.7442	0.7461	0.7480	0.7496	0.7516	0.7532	0.7548	0.7565	0.7580	0.7595
Jiangdu	0.5394	0.5388	0.5382	0.5377	0.5371	0.5365	0.5359	0.5353	0.5348	0.5343	0.5337	0.5332	0.5327	0.5323	0.5318
Danyang	0.7580	0.7606	0.7628	0.7650	0.7671	0.7691	0.7712	0.7733	0.7753	0.7775	0.7796	0.7817	0.7835	0.7855	0.7873
Yangzhong	0.6245	0.6238	0.6231	0.6224	0.6217	0.6210	0.6204	0.6197	0.6191	0.6185	0.6179	0.6173	0.6167	0.6161	0.6156
Jurong	0.7043	0.7065	0.7086	0.7108	0.7130	0.7155	0.7178	0.7198	0.7217	0.7237	0.7257	0.7277	0.7298	0.7318	0.7337
Taizhou	0.5878	0.5872	0.5865	0.5859	0.5852	0.5846	0.5840	0.5834	0.5828	0.5822	0.5816	0.5811	0.5805	0.5800	0.5795
Jingjiang	0.7095	0.7087	0.7080	0.7072	0.7064	0.7057	0.7050	0.7042	0.7035	0.7028	0.7022	0.7015	0.7009	0.7003	0.6997
Taixing	0.7141	0.7133	0.7125	0.7117	0.7109	0.7102	0.7094	0.7087	0.7079	0.7072	0.7065	0.7059	0.7052	0.7046	0.7039
Jiangyan	0.4207	0.4202	0.4198	0.4193	0.4189	0.4184	0.4180	0.4175	0.4171	0.4167	0.4163	0.4159	0.4155	0.4151	0.4147
Fuyang	0.5630	0.5631	0.5630	0.5630	0.5633	0.5633	0.5631	0.5633	0.5630	0.5629	0.5626	0.5624	0.5624	0.5620	0.5618
Linan	0.6292	0.6288	0.6283	0.6280	0.6276	0.6275	0.6271	0.6270	0.6267	0.6264	0.6262	0.6259	0.6255	0.6253	0.6250
Yuyao	0.7308	0.7332	0.7353	0.7375	0.7396	0.7416	0.7435	0.7456	0.7473	0.7490	0.7507	0.7524	0.7540	0.7555	0.7567
Cixi	0.8144	0.8142	0.8139	0.8136	0.8134	0.8131	0.8129	0.8126	0.8124	0.8121	0.8119	0.8117	0.8114	0.8111	0.8108
Xiucheng	0.7586	0.7599	0.7612	0.7625	0.7636	0.7649	0.7662	0.7674	0.7685	0.7698	0.7711	0.7723	0.7734	0.7744	0.7755
Xiuzhou	0.7428	0.7442	0.7455	0.7467	0.7480	0.7492	0.7505	0.7518	0.7531	0.7545	0.7558	0.7571	0.7584	0.7595	0.7607
Jiashan	0.7430	0.7445	0.7459	0.7472	0.7484	0.7495	0.7505	0.7519	0.7531	0.7544	0.7555	0.7566	0.7578	0.7591	0.7602
Haiyan	0.6548	0.6589	0.6627	0.6669	0.6700	0.6738	0.6770	0.6803	0.6832	0.6862	0.6890	0.6921	0.6949	0.6979	0.7007
Haining	0.7739	0.7765	0.7790	0.7813	0.7838	0.7862	0.7884	0.7905	0.7926	0.7945	0.7965	0.7983	0.8000	0.8018	0.8035
Pinghu	0.7179	0.7191	0.7201	0.7215	0.7229	0.7242	0.7254	0.7266	0.7280	0.7293	0.7307	0.7322	0.7337	0.7348	0.7362
Tongxiang	0.7479	0.7496	0.7510	0.7526	0.7542	0.7557	0.7573	0.7589	0.7603	0.7617	0.7630	0.7644	0.7659	0.7671	0.7685
Huzhou	0.7699	0.7699	0.7701	0.7703	0.7705	0.7706	0.7708	0.7709	0.7712	0.7715	0.7718	0.7721	0.7724	0.7726	0.7728
Deqing	0.7163	0.7172	0.7182	0.7190	0.7199	0.7209	0.7216	0.7224	0.7236	0.7245	0.7255	0.7265	0.7275	0.7285	0.7294
Changxing	0.7251	0.7267	0.7279	0.7293	0.7309	0.7323	0.7338	0.7352	0.7367	0.7382	0.7394	0.7407	0.7422	0.7437	0.7451
Anji	0.6862	0.6857	0.6851	0.6845	0.6840	0.6834	0.6830	0.6825	0.6821	0.6817	0.6812	0.6808	0.6805	0.6801	0.6797
Shangyu	0.6008	0.6014	0.6019	0.6021	0.6021	0.6025	0.6029	0.6034	0.6038	0.6043	0.6043	0.6043	0.6045	0.6048	0.6050
Wuhu	0.2459	0.2456	0.2453	0.2451	0.2448	0.2445	0.2443	0.2440	0.2438	0.2435	0.2433	0.2430	0.2428	0.2426	0.2424
Xiangshan	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Dangtu	0.5653	0.5650	0.5647	0.5644	0.5641	0.5640	0.5637	0.5638	0.5636	0.5636	0.5632	0.5631	0.5629	0.5628	0.5627
Xuancheng	0.6211	0.6204	0.6197	0.6191	0.6184	0.6177	0.6171	0.6164	0.6158	0.6152	0.6146	0.6140	0.6134	0.6129	0.6123
Langxi	0.5364	0.5359	0.5354	0.5348	0.5342	0.5337	0.5332	0.5329	0.5326	0.5320	0.5315	0.5311	0.5307	0.5302	0.5298
Guangde	0.5956	0.5949	0.5942	0.5936	0.5929	0.5923	0.5917	0.5911	0.5904	0.5899	0.5893	0.5887	0.5882	0.5876	0.5871
Jingxian	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Jixi	0.4078	0.4074	0.4069	0.4065	0.4060	0.4056	0.4052	0.4047	0.4043	0.4039	0.4035	0.4031	0.4028	0.4024	0.4020
Jingde	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ningguo	0.5903	0.5897	0.5890	0.5884	0.5877	0.5871	0.5865	0.5859	0.5853	0.5847	0.5841	0.5836	0.5830	0.5825	0.5820

Table 22. Normalization of scenario 3: ecological system concerns, plus development corridors urban growth prediction by city, 2016-2030.

iv. Scenario 4: disaster prevention, plus development corridors

As before, the results of city-level urban growth prediction were reproduced here. Figures 93, 94, and 95 show the urban growth prediction outcomes from scenario 4: disaster prevention, plus development corridors by city from 2016 to 2030. The Scenario Cellular Automata model was used, once again, to predict from 2011 to 2030 and data from 2011 to 2015 were not presented here. Table 19 shows scenario 4: disaster prevention, plus development corridors urban growth prediction by city, Table 20 shows the urban growth prediction data processed by natural logarithms, and Table 21 shows the normalization of the urban growth prediction.

In much the same way, as the previous three scenario projections, during the prediction period, the urbanization area, represented by grid pixels, of each city grew at different rates with much the same outcomes as described earlier.

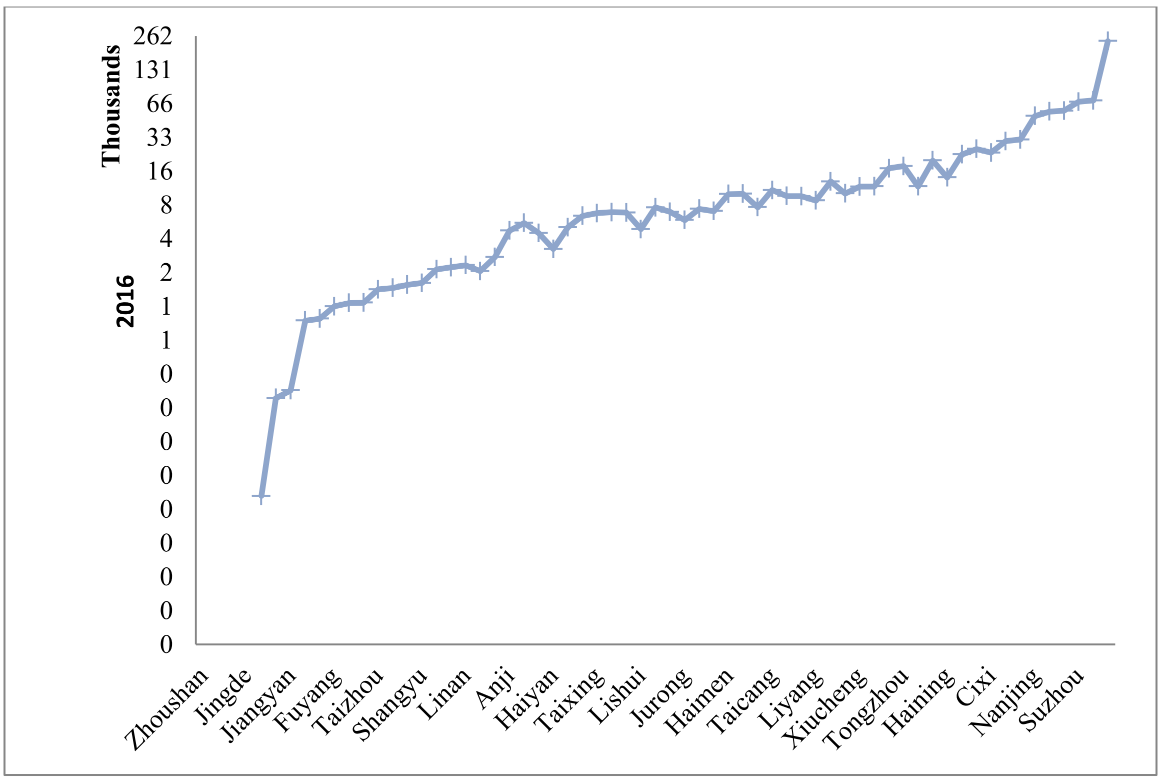


Figure 93. Logarithmic ranking of cities and towns in 2016 for scenario 4: disaster prevention, plus development corridors.

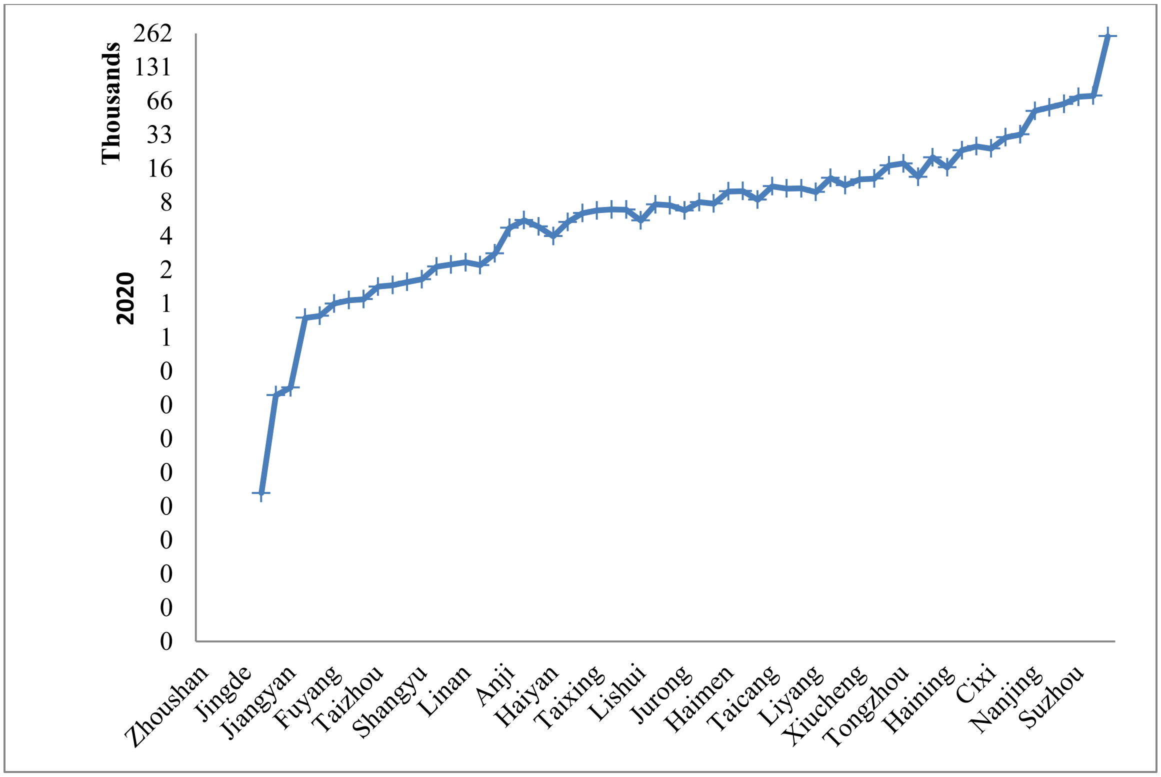


Figure 94. Logarithmic ranking of cities and towns in 2020 for scenario 4: disaster prevention, plus development corridors.

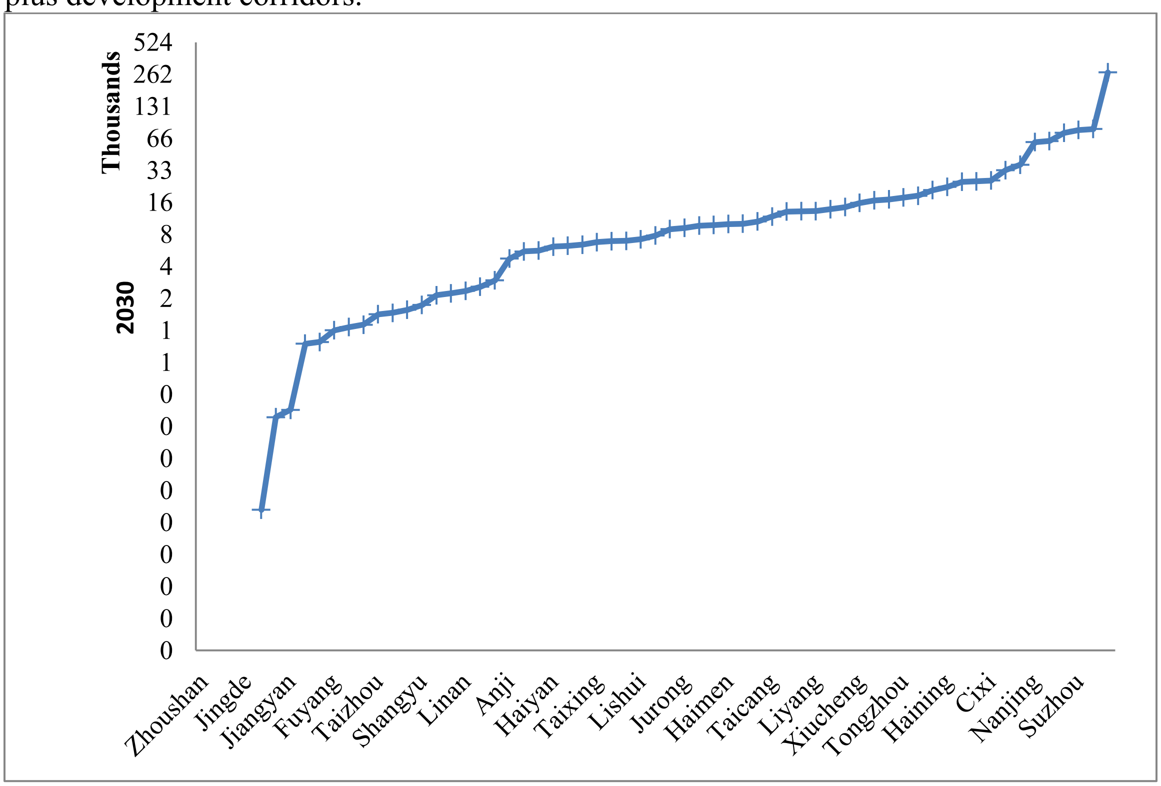


Figure 95. Logarithmic ranking of cities and towns in 2030 for scenario 4: disaster prevention, plus development corridors.

City	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Zhoushan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Xiangshan	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Jingxian	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Jingde	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wuhu	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21
Jixi	156	156	156	156	156	156	156	156	156	156	156	156	156	156	156
Jiangyan	183	183	183	183	183	183	183	183	183	183	183	183	183	183	183
Langxi	766	766	766	766	766	766	766	766	766	766	766	766	766	766	766
Jiangdu	796	796	796	796	796	796	796	796	796	796	796	796	796	796	796
Fuyang	1026	1026	1026	1026	1026	1026	1026	1026	1026	1026	1026	1026	1026	1026	1026
Rudong	1099	1099	1099	1099	1099	1099	1099	1099	1099	1099	1099	1099	1099	1099	1099
Dangtu	1104	1110	1113	1119	1120	1125	1126	1132	1136	1138	1144	1149	1151	1154	1158
Taizhou	1449	1449	1449	1449	1449	1449	1449	1449	1449	1449	1449	1449	1449	1449	1449
Ningguo	1495	1495	1495	1495	1495	1495	1495	1495	1495	1495	1495	1495	1495	1495	1495
Guangde	1595	1596	1596	1596	1596	1596	1596	1596	1596	1596	1596	1596	1596	1596	1596
Shangyu	1654	1661	1669	1679	1687	1696	1710	1715	1722	1733	1745	1751	1756	1762	1770
Xuancheng	2189	2189	2189	2189	2189	2189	2189	2189	2189	2189	2189	2189	2189	2189	2189
Yangzhong	2281	2281	2281	2281	2281	2281	2281	2281	2281	2281	2281	2281	2281	2281	2281
Linan	2384	2386	2387	2387	2390	2390	2390	2390	2391	2393	2395	2396	2398	2401	2404
Ningbo	2106	2137	2181	2220	2251	2288	2324	2368	2405	2444	2481	2513	2553	2586	2626
Gaochun	2811	2824	2838	2853	2863	2876	2888	2899	2914	2939	2956	2973	2988	3000	3017
Anji	4838	4838	4838	4838	4838	4838	4838	4838	4839	4839	4840	4840	4840	4841	4842
Rugao	5666	5666	5666	5666	5666	5666	5666	5666	5666	5666	5666	5666	5666	5666	5666
Shaoxing	4609	4703	4798	4892	4970	5049	5122	5203	5279	5364	5454	5526	5606	5683	5762
Haiyan	3320	3506	3682	3875	4074	4253	4458	4657	4881	5105	5327	5556	5778	6036	6272
Jintan	5178	5240	5311	5384	5461	5539	5618	5681	5786	5893	5996	6082	6191	6286	6376
Jingjiang	6542	6542	6542	6542	6543	6543	6544	6544	6544	6545	6545	6546	6547	6548	6549
Taixing	6920	6920	6920	6920	6920	6920	6920	6920	6920	6920	6920	6920	6920	6920	6920
Nantong	7064	7064	7064	7064	7064	7064	7064	7064	7064	7064	7064	7064	7064	7064	7064
Yizheng	7006	7015	7028	7034	7039	7048	7057	7061	7072	7079	7084	7088	7097	7104	7112
Lishui	4985	5153	5299	5457	5631	5802	5957	6127	6300	6483	6641	6813	7002	7183	7359
Yangzhou	7779	7790	7804	7822	7842	7851	7866	7877	7886	7897	7911	7922	7936	7948	7959
Deqing	7112	7254	7395	7545	7693	7834	7993	8148	8279	8420	8554	8700	8870	9023	9166
Jurong	6015	6218	6451	6671	6929	7173	7408	7651	7869	8109	8354	8619	8859	9153	9423
Yuyao	7573	7743	7893	8040	8218	8398	8556	8723	8897	9050	9218	9378	9556	9717	9865
Pinghu	7230	7405	7609	7800	7980	8169	8343	8534	8713	8931	9140	9359	9569	9792	10018
Haimen	10222	10222	10222	10222	10222	10222	10222	10222	10222	10222	10222	10222	10222	10222	10222
Qidong	10302	10302	10302	10302	10302	10302	10302	10302	10302	10302	10302	10302	10302	10302	10302
Changxing	7810	7993	8207	8425	8636	8834	9024	9241	9447	9673	9901	10134	10347	10570	10816
Taicang	11118	11178	11236	11298	11371	11425	11502	11565	11638	11704	11763	11831	11895	11974	12033
Jiashan	9848	10089	10334	10620	10856	11087	11377	11622	11877	12102	12385	12654	12904	13153	13416
Xiuzhou	9799	10073	10349	10622	10895	11149	11396	11664	11917	12198	12457	12720	12993	13251	13511
Liyang	8957	9223	9511	9801	10095	10416	10733	11042	11389	11728	12055	12423	12781	13177	13537
Huzhou	13252	13302	13362	13422	13479	13524	13583	13648	13715	13775	13826	13891	13963	14025	14099
Tongxiang	10363	10666	10964	11288	11599	11897	12225	12542	12860	13142	13451	13785	14079	14417	14751
Xiucheng	11919	12201	12499	12794	13071	13375	13694	13967	14285	14602	14914	15242	15546	15849	16137
Zhenjiang	11987	12316	12650	12956	13297	13646	14031	14405	14739	15102	15485	15854	16248	16660	17076
Wujiang	17353	17361	17369	17377	17382	17385	17392	17397	17407	17414	17423	17428	17429	17431	17437
Tongzhou	18186	18186	18186	18186	18186	18186	18186	18186	18186	18186	18186	18186	18186	18186	18186
Danyang	11963	12401	12875	13307	13772	14267	14805	15306	15799	16278	16797	17296	17829	18341	18864
Changshu	20371	20420	20479	20524	20580	20648	20723	20806	20890	20965	21045	21108	21182	21264	21335
Haining	14376	14951	15546	16140	16731	17357	17946	18541	19177	19797	20387	21013	21625	22250	22834
Yixing	23061	23238	23448	23604	23801	23973	24154	24359	24541	24720	24886	25053	25226	25410	25577
ngjiagang	25788	25788	25788	25788	25788	25788	25788	25788	25788	25788	25788	25788	25788	25788	25788
Cixi	23925	24105	24258	24426	24622	24818	25001	25180	25356	25515	25652	25811	25965	26110	26255
Kunshan	30278	30465	30648	30833	31031	31199	31378	31549	31745	31923	32107	32303	32509	32697	32891
Jiangyin	31336	31707	32096	32479	32888	33307	33703	34127	34544	34947	35353	35741	36133	36546	36993
Nanjing	50710	51333	51949	52592	53260	53925	54616	55284	55989	56672	57409	58139	58891	59553	60223
Wuxi	55555	56054	56514	56973	57404	57871	58314	58773	59185	59625	60066	60511	60935	61355	61751
Changzhou	56558	57828	59046	60341	61617	62893	64110	65359	66566	67820	69139	70350	71524	72643	73739
Suzhou	68079	68855	69618	70382	71131	71877	72634	73402	74149	74874	75565	76280	77043	77777	78444
Hangzhou	69795	70530	71300	72057	72843	73621	74373	75130	75854	76578	77279	78019	78724	79427	80109
Shanghai	236036	238900	241675	244461	247203	249974	252685	255344	258058	260646	263290	265846	268399	270865	273340

Table 23. Scenario 4: disaster prevention, plus development corridors urban growth prediction by city, 2016-2030.

City	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Zhoushan	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Wuxi	10.9251	10.9341	10.9422	10.9503	10.9579	10.9660	10.9736	10.9814	10.9884	10.9958	11.0032	11.0106	11.0176	11.0244	11.0309
Changzhou	10.9430	10.9652	10.9861	11.0078	11.0287	11.0492	11.0684	11.0877	11.1059	11.1246	11.1439	11.1612	11.1778	11.1933	11.2083
Shanghai	12.3717	12.3838	12.3953	12.4068	12.4180	12.4291	12.4399	12.4504	12.4609	12.4709	12.4810	12.4907	12.5002	12.5094	12.5185
Ningbo	7.6525	7.6672	7.6875	7.7053	7.7191	7.7354	7.7510	7.7698	7.7853	7.8014	7.8164	7.8292	7.8450	7.8579	7.8732
Suzhou	11.1284	11.1398	11.1508	11.1617	11.1723	11.1827	11.1932	11.2037	11.2138	11.2236	11.2327	11.2422	11.2521	11.2616	11.2701
Zhenjiang	9.3916	9.4187	9.4454	9.4693	9.4953	9.5212	9.5490	9.5753	9.5983	9.6226	9.6476	9.6712	9.6957	9.7208	9.7454
Nanjing	10.8339	10.8461	10.8580	10.8703	10.8829	10.8953	10.9081	10.9202	10.9329	10.9450	10.9580	10.9706	10.9834	10.9946	11.0058
Nantong	8.8628	8.8628	8.8628	8.8628	8.8628	8.8628	8.8628	8.8628	8.8628	8.8628	8.8628	8.8628	8.8628	8.8628	8.8628
Hangzhou	11.1533	11.1638	11.1747	11.1852	11.1961	11.2067	11.2168	11.2270	11.2366	11.2461	11.2552	11.2647	11.2737	11.2826	11.2911
Shaoxing	8.4358	8.4560	8.4760	8.4954	8.5112	8.5269	8.5413	8.5570	8.5715	8.5875	8.6041	8.6172	8.6316	8.6452	8.6590
Lishui	8.5142	8.5473	8.5753	8.6047	8.6360	8.6660	8.6923	8.7205	8.7483	8.7769	8.8010	8.8266	8.8540	8.8795	8.9037
Gaochun	7.9413	7.9459	7.9509	7.9561	7.9596	7.9642	7.9683	7.9721	7.9773	7.9858	7.9916	7.9973	8.0024	8.0064	8.0120
Jiangyin	10.3525	10.3643	10.3765	10.3883	10.4009	10.4135	10.4253	10.4378	10.4500	10.4616	10.4731	10.4841	10.4950	10.5063	10.5185
Yixing	10.0459	10.0535	10.0625	10.0692	10.0775	10.0847	10.0922	10.1007	10.1081	10.1154	10.1221	10.1287	10.1356	10.1429	10.1494
Liyang	9.1002	9.1295	9.1602	9.1902	9.2198	9.2511	9.2811	9.3095	9.3404	9.3697	9.3972	9.4273	9.4557	9.4862	9.5132
Jintan	8.5522	8.5641	8.5775	8.5912	8.6054	8.6196	8.6337	8.6449	8.6632	8.6815	8.6988	8.7131	8.7309	8.7461	8.7603
Changshu	9.9219	9.9243	9.9272	9.9294	9.9321	9.9354	9.9390	9.9430	9.9470	9.9506	9.9544	9.9574	9.9609	9.9648	9.9681
ngjiagang	10.1577	10.1577	10.1577	10.1577	10.1577	10.1577	10.1577	10.1577	10.1577	10.1577	10.1577	10.1577	10.1577	10.1577	10.1577
Kunshan	10.3182	10.3243	10.3303	10.3363	10.3427	10.3481	10.3539	10.3593	10.3655	10.3711	10.3768	10.3829	10.3893	10.3950	10.4010
Wujiang	9.7615	9.7620	9.7624	9.7629	9.7632	9.7634	9.7638	9.7641	9.7646	9.7650	9.7655	9.7658	9.7659	9.7660	9.7663
Taicang	9.3163	9.3217	9.3269	9.3324	9.3388	9.3436	9.3503	9.3557	9.3620	9.3677	9.3727	9.3785	9.3839	9.3905	9.3954
Rudong	7.0022	7.0022	7.0022	7.0022	7.0022	7.0022	7.0022	7.0022	7.0022	7.0022	7.0022	7.0022	7.0022	7.0022	7.0022
Qidong	9.2401	9.2401	9.2401	9.2401	9.2401	9.2401	9.2401	9.2401	9.2401	9.2401	9.2401	9.2401	9.2401	9.2401	9.2401
Rugao	8.6422	8.6422	8.6422	8.6422	8.6422	8.6422	8.6422	8.6422	8.6422	8.6422	8.6422	8.6422	8.6422	8.6422	8.6422
Tongzhou	9.8084	9.8084	9.8084	9.8084	9.8084	9.8084	9.8084	9.8084	9.8084	9.8084	9.8084	9.8084	9.8084	9.8084	9.8084
Haimen	9.2323	9.2323	9.2323	9.2323	9.2323	9.2323	9.2323	9.2323	9.2323	9.2323	9.2323	9.2323	9.2323	9.2323	9.2323
Yangzhou	8.9592	8.9606	8.9624	8.9647	8.9672	8.9684	8.9703	8.9717	8.9728	8.9742	8.9760	8.9774	8.9792	8.9807	8.9821
Yizheng	8.8545	8.8558	8.8577	8.8585	8.8592	8.8605	8.8618	8.8623	8.8639	8.8649	8.8656	8.8662	8.8674	8.8684	8.8695
Jiangdu	6.6796	6.6796	6.6796	6.6796	6.6796	6.6796	6.6796	6.6796	6.6796	6.6796	6.6796	6.6796	6.6796	6.6796	6.6796
Danyang	9.3896	9.4255	9.4630	9.4960	9.5304	9.5657	9.6027	9.6360	9.6677	9.6976	9.7290	9.7582	9.7886	9.8169	9.8450
Yangzhong	7.7324	7.7324	7.7324	7.7324	7.7324	7.7324	7.7324	7.7324	7.7324	7.7324	7.7324	7.7324	7.7324	7.7324	7.7324
Jurong	8.7020	8.7352	8.7720	8.8055	8.8435	8.8781	8.9103	8.9426	8.9707	9.0007	9.0305	9.0617	9.0892	9.1218	9.1509
Taizhou	7.2786	7.2786	7.2786	7.2786	7.2786	7.2786	7.2786	7.2786	7.2786	7.2786	7.2786	7.2786	7.2786	7.2786	7.2786
Jingjiang	8.7860	8.7860	8.7860	8.7860	8.7862	8.7862	8.7863	8.7863	8.7863	8.7865	8.7865	8.7866	8.7868	8.7869	8.7871
Taixing	8.8422	8.8422	8.8422	8.8422	8.8422	8.8422	8.8422	8.8422	8.8422	8.8422	8.8422	8.8422	8.8422	8.8422	8.8422
Jiangyan	5.2095	5.2095	5.2095	5.2095	5.2095	5.2095	5.2095	5.2095	5.2095	5.2095	5.2095	5.2095	5.2095	5.2095	5.2095
Fuyang	6.9334	6.9334	6.9334	6.9334	6.9334	6.9334	6.9334	6.9334	6.9334	6.9334	6.9334	6.9334	6.9334	6.9334	6.9334
Linan	7.7765	7.7774	7.7778	7.7778	7.7790	7.7790	7.7790	7.7790	7.7795	7.7803	7.7811	7.7816	7.7824	7.7836	7.7849
Yuyao	8.9323	8.9545	8.9737	8.9922	9.0141	9.0357	9.0544	9.0737	9.0935	9.1105	9.1289	9.1461	9.1649	9.1816	9.1967
Cixi	10.0827	10.0902	10.0965	10.1034	10.1114	10.1193	10.1267	10.1338	10.1408	10.1470	10.1524	10.1586	10.1645	10.1701	10.1756
Xiucheng	9.3859	9.4093	9.4334	9.4567	9.4782	9.5011	9.5247	9.5445	9.5670	9.5889	9.6101	9.6318	9.6516	9.6709	9.6889
Xiuzhou	9.1900	9.2176	9.2446	9.2707	9.2961	9.3191	9.3410	9.3643	9.3857	9.4090	9.4300	9.4509	9.4722	9.4918	9.5113
Jiashan	9.1950	9.2192	9.2432	9.2705	9.2925	9.3135	9.3393	9.3607	9.3824	9.4011	9.4242	9.4457	9.4653	9.4844	9.5042
Haiyan	8.1077	8.1622	8.2112	8.2623	8.3124	8.3554	8.4025	8.4461	8.4931	8.5380	8.5805	8.6226	8.6618	8.7055	8.7439
Haining	9.5733	9.6125	9.6516	9.6891	9.7250	9.7618	9.7951	9.8277	9.8615	9.8933	9.9227	9.9529	9.9816	10.0101	10.0360
Pinghu	8.8860	8.9099	8.9371	8.9619	8.9847	9.0081	9.0292	9.0518	9.0726	9.0973	9.1204	9.1441	9.1663	9.1893	9.2121
Tongxiang	9.2460	9.2748	9.3024	9.3315	9.3587	9.3840	9.4112	9.4368	9.4619	9.4836	9.5068	9.5313	9.5524	9.5762	9.5991
Huzhou	9.4919	9.4957	9.5002	9.5047	9.5089	9.5122	9.5166	9.5213	9.5262	9.5306	9.5343	9.5390	9.5442	9.5486	9.5539
Deqing	8.8695	8.8893	8.9086	8.9286	8.9481	8.9662	8.9863	9.0055	9.0215	9.0384	9.0542	9.0711	9.0904	9.1075	9.1233
Changxing	8.9632	8.9863	9.0127	9.0390	9.0637	9.0864	9.1076	9.1314	9.1535	9.1771	9.2004	9.2237	9.2445	9.2658	9.2888
Anji	8.4843	8.4843	8.4843	8.4843	8.4843	8.4843	8.4843	8.4843	8.4845	8.4845	8.4847	8.4847	8.4847	8.4849	8.4851
Shangyu	7.4110	7.4152	7.4200	7.4260	7.4307	7.4360	7.4442	7.4472	7.4512	7.4576	7.4645	7.4679	7.4708	7.4742	7.4787
Wuhu	3.0445	3.0445	3.0445	3.0445	3.0445	3.0445	3.0445	3.0445	3.0445	3.0445	3.0445	3.0445	3.0445	3.0445	3.0445
Xiangshan	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Dangtu	7.0067	7.0121	7.0148	7.0202	7.0211	7.0255	7.0264	7.0317	7.0353	7.0370	7.0423	7.0466	7.0484	7.0510	7.0544
Xuancheng	7.6912	7.6912	7.6912	7.6912	7.6912	7.6912	7.6912	7.6912	7.6912	7.6912	7.6912	7.6912	7.6912	7.6912	7.6912
Langxi	6.6412	6.6412	6.6412	6.6412	6.6412	6.6412	6.6412	6.6412	6.6412	6.6412	6.6412	6.6412	6.6412	6.6412	6.6412
Guangde	7.3746	7.3753	7.3753	7.3753	7.3753	7.3753	7.3753	7.3753	7.3753	7.3753	7.3753	7.3753	7.3753	7.3753	7.3753
Jingxian	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Jixi	5.0499	5.0499	5.0499	5.0499	5.0499	5.0499	5.0499	5.0499	5.0499	5.0499	5.0499	5.0499	5.0499	5.0499	5.0499
Jingde	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ningguo	7.3099	7.3099	7.3099	7.3099	7.3099	7.3099	7.3099	7.3099	7.3099	7.3099	7.3099	7.3099	7.3099	7.3099	7.3099

Table 24. Natural logarithms of scenario 4: disaster prevention, plus development corridors urban growth prediction by city, 2016-2030.

City	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Zhoushan	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Wuxi	0.8831	0.8829	0.8828	0.8826	0.8824	0.8823	0.8821	0.8820	0.8818	0.8817	0.8816	0.8815	0.8814	0.8813	0.8812
Changzhou	0.8845	0.8854	0.8863	0.8872	0.8881	0.8890	0.8897	0.8905	0.8913	0.8920	0.8929	0.8936	0.8942	0.8948	0.8953
Shanghai	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Ningbo	0.6186	0.6191	0.6202	0.6211	0.6216	0.6224	0.6231	0.6241	0.6248	0.6256	0.6263	0.6268	0.6276	0.6282	0.6289
Suzhou	0.8995	0.8995	0.8996	0.8996	0.8997	0.8997	0.8998	0.8999	0.8999	0.9000	0.9000	0.9000	0.9002	0.9003	0.9003
Zhenjiang	0.7591	0.7606	0.7620	0.7632	0.7646	0.7660	0.7676	0.7691	0.7703	0.7716	0.7730	0.7743	0.7756	0.7771	0.7785
Nanjing	0.8757	0.8758	0.8760	0.8762	0.8764	0.8766	0.8769	0.8771	0.8774	0.8776	0.8780	0.8783	0.8787	0.8789	0.8792
Nantong	0.7164	0.7157	0.7150	0.7143	0.7137	0.7131	0.7124	0.7118	0.7112	0.7107	0.7101	0.7096	0.7090	0.7085	0.7080
Hangzhou	0.9015	0.9015	0.9015	0.9015	0.9016	0.9016	0.9017	0.9017	0.9017	0.9018	0.9018	0.9018	0.9019	0.9019	0.9020
Shaoxing	0.6819	0.6828	0.6838	0.6847	0.6854	0.6860	0.6866	0.6873	0.6879	0.6886	0.6894	0.6899	0.6905	0.6911	0.6917
Lishui	0.6882	0.6902	0.6918	0.6935	0.6954	0.6972	0.6987	0.7004	0.7021	0.7038	0.7052	0.7067	0.7083	0.7098	0.7112
Gaochun	0.6419	0.6416	0.6414	0.6413	0.6410	0.6408	0.6405	0.6403	0.6402	0.6404	0.6403	0.6403	0.6402	0.6400	0.6400
Jiangyin	0.8368	0.8369	0.8371	0.8373	0.8376	0.8378	0.8381	0.8384	0.8386	0.8389	0.8391	0.8394	0.8396	0.8399	0.8402
Yixing	0.8120	0.8118	0.8118	0.8116	0.8115	0.8114	0.8113	0.8113	0.8112	0.8111	0.8110	0.8109	0.8108	0.8108	0.8108
Liyang	0.7356	0.7372	0.7390	0.7407	0.7425	0.7443	0.7461	0.7477	0.7496	0.7513	0.7529	0.7547	0.7564	0.7583	0.7599
Jintan	0.6913	0.6916	0.6920	0.6925	0.6930	0.6935	0.6940	0.6943	0.6952	0.6961	0.6970	0.6976	0.6985	0.6992	0.6998
Changshu	0.8020	0.8014	0.8009	0.8003	0.7998	0.7994	0.7990	0.7986	0.7983	0.7979	0.7976	0.7972	0.7969	0.7966	0.7963
ngjiagang	0.8210	0.8202	0.8195	0.8187	0.8180	0.8172	0.8165	0.8159	0.8152	0.8145	0.8138	0.8132	0.8126	0.8120	0.8114
Kunshan	0.8340	0.8337	0.8334	0.8331	0.8329	0.8326	0.8323	0.8320	0.8318	0.8316	0.8314	0.8313	0.8311	0.8310	0.8308
Wujiang	0.7890	0.7883	0.7876	0.7869	0.7862	0.7855	0.7849	0.7842	0.7836	0.7830	0.7824	0.7819	0.7813	0.7807	0.7802
Taicang	0.7530	0.7527	0.7524	0.7522	0.7520	0.7517	0.7516	0.7514	0.7513	0.7512	0.7510	0.7508	0.7507	0.7507	0.7505
Rudong	0.5660	0.5654	0.5649	0.5644	0.5639	0.5634	0.5629	0.5624	0.5619	0.5615	0.5610	0.5606	0.5602	0.5598	0.5593
Qidong	0.7469	0.7461	0.7454	0.7448	0.7441	0.7434	0.7428	0.7422	0.7415	0.7409	0.7403	0.7398	0.7392	0.7387	0.7381
Rugao	0.6985	0.6979	0.6972	0.6966	0.6959	0.6953	0.6947	0.6941	0.6935	0.6930	0.6924	0.6919	0.6914	0.6909	0.6904
Tongzhou	0.7928	0.7920	0.7913	0.7906	0.7899	0.7891	0.7885	0.7878	0.7871	0.7865	0.7859	0.7853	0.7847	0.7841	0.7835
Haimen	0.7462	0.7455	0.7448	0.7441	0.7435	0.7428	0.7422	0.7415	0.7409	0.7403	0.7397	0.7391	0.7386	0.7380	0.7375
Yangzhou	0.7242	0.7236	0.7230	0.7226	0.7221	0.7216	0.7211	0.7206	0.7201	0.7196	0.7192	0.7187	0.7183	0.7179	0.7175
Yizheng	0.7157	0.7151	0.7146	0.7140	0.7134	0.7129	0.7124	0.7118	0.7113	0.7108	0.7103	0.7098	0.7094	0.7089	0.7085
Jiangdu	0.5399	0.5394	0.5389	0.5384	0.5379	0.5374	0.5369	0.5365	0.5360	0.5356	0.5352	0.5348	0.5344	0.5340	0.5336
Danyang	0.7590	0.7611	0.7634	0.7654	0.7675	0.7696	0.7719	0.7740	0.7758	0.7776	0.7795	0.7812	0.7831	0.7848	0.7864
Yangzhong	0.6250	0.6244	0.6238	0.6232	0.6227	0.6221	0.6216	0.6211	0.6205	0.6200	0.6195	0.6191	0.6186	0.6181	0.6177
Jurong	0.7034	0.7054	0.7077	0.7097	0.7122	0.7143	0.7163	0.7183	0.7199	0.7217	0.7235	0.7255	0.7271	0.7292	0.7310
Taizhou	0.5883	0.5878	0.5872	0.5867	0.5861	0.5856	0.5851	0.5846	0.5841	0.5836	0.5832	0.5827	0.5823	0.5819	0.5814
Jingjiang	0.7102	0.7095	0.7088	0.7082	0.7075	0.7069	0.7063	0.7057	0.7051	0.7046	0.7040	0.7035	0.7029	0.7024	0.7019
Taixing	0.7147	0.7140	0.7133	0.7127	0.7120	0.7114	0.7108	0.7102	0.7096	0.7090	0.7084	0.7079	0.7074	0.7068	0.7063
Jiangyan	0.4211	0.4207	0.4203	0.4199	0.4195	0.4191	0.4188	0.4184	0.4181	0.4177	0.4174	0.4171	0.4168	0.4164	0.4161
Fuyang	0.5604	0.5599	0.5594	0.5588	0.5583	0.5578	0.5574	0.5569	0.5564	0.5560	0.5555	0.5551	0.5547	0.5543	0.5539
Linan	0.6286	0.6280	0.6275	0.6269	0.6264	0.6259	0.6253	0.6248	0.6243	0.6239	0.6234	0.6230	0.6226	0.6222	0.6219
Yuyao	0.7220	0.7231	0.7240	0.7248	0.7259	0.7270	0.7279	0.7288	0.7298	0.7305	0.7314	0.7322	0.7332	0.7340	0.7347
Cixi	0.8150	0.8148	0.8145	0.8143	0.8143	0.8142	0.8140	0.8139	0.8138	0.8137	0.8134	0.8133	0.8131	0.8130	0.8128
Xiucheng	0.7587	0.7598	0.7610	0.7622	0.7633	0.7644	0.7657	0.7666	0.7678	0.7689	0.7700	0.7711	0.7721	0.7731	0.7740
Xiuzhou	0.7428	0.7443	0.7458	0.7472	0.7486	0.7498	0.7509	0.7521	0.7532	0.7545	0.7556	0.7566	0.7578	0.7588	0.7598
Jiashan	0.7432	0.7445	0.7457	0.7472	0.7483	0.7493	0.7508	0.7518	0.7529	0.7538	0.7551	0.7562	0.7572	0.7582	0.7592
Haiyan	0.6553	0.6591	0.6624	0.6659	0.6694	0.6722	0.6754	0.6784	0.6816	0.6846	0.6875	0.6903	0.6929	0.6959	0.6985
Haining	0.7738	0.7762	0.7786	0.7809	0.7831	0.7854	0.7874	0.7894	0.7914	0.7933	0.7950	0.7968	0.7985	0.8002	0.8017
Pinghu	0.7182	0.7195	0.7210	0.7223	0.7235	0.7248	0.7258	0.7270	0.7281	0.7295	0.7307	0.7321	0.7333	0.7346	0.7359
Tongxiang	0.7473	0.7489	0.7505	0.7521	0.7536	0.7550	0.7565	0.7580	0.7593	0.7605	0.7617	0.7631	0.7642	0.7655	0.7668
Huzhou	0.7672	0.7668	0.7664	0.7661	0.7657	0.7653	0.7650	0.7647	0.7645	0.7642	0.7639	0.7637	0.7635	0.7633	0.7632
Deqing	0.7169	0.7178	0.7187	0.7197	0.7206	0.7214	0.7224	0.7233	0.7240	0.7248	0.7254	0.7262	0.7272	0.7281	0.7288
Changxing	0.7245	0.7257	0.7271	0.7285	0.7299	0.7311	0.7321	0.7334	0.7346	0.7359	0.7372	0.7384	0.7395	0.7407	0.7420
Anji	0.6858	0.6851	0.6845	0.6838	0.6832	0.6826	0.6820	0.6814	0.6809	0.6803	0.6798	0.6793	0.6788	0.6783	0.6778
Shangyu	0.5990	0.5988	0.5986	0.5985	0.5984	0.5983	0.5984	0.5981	0.5980	0.5980	0.5981	0.5979	0.5977	0.5975	0.5974
Wuhu	0.2461	0.2458	0.2456	0.2454	0.2452	0.2450	0.2447	0.2445	0.2443	0.2441	0.2439	0.2437	0.2436	0.2434	0.2432
Xiangshan	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Dangtu	0.5663	0.5662	0.5659	0.5658	0.5654	0.5652	0.5648	0.5648	0.5646	0.5643	0.5642	0.5642	0.5639	0.5637	0.5635
Xuancheng	0.6217	0.6211	0.6205	0.6199	0.6194	0.6188	0.6183	0.6177	0.6172	0.6167	0.6162	0.6158	0.6153	0.6148	0.6144
Langxi	0.5368	0.5363	0.5358	0.5353	0.5348	0.5343	0.5339	0.5334	0.5330	0.5325	0.5321	0.5317	0.5313	0.5309	0.5305
Guangde	0.5961	0.5956	0.5950	0.5945	0.5939	0.5934	0.5929	0.5924	0.5919	0.5914	0.5909	0.5905	0.5900	0.5896	0.5891
Jingxian	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Jixi	0.4082	0.4078	0.4074	0.4070	0.4067	0.4063	0.4059	0.4056	0.4053	0.4049	0.4046	0.4043	0.4040	0.4037	0.4034
Jingde	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Ningguo	0.5909	0.5903	0.5897	0.5892	0.5887	0.5881	0.5876	0.5871	0.5866	0.5862	0.5857	0.5852	0.5848	0.5844	0.5839

Table 25. Normalization of scenario 4: disaster prevention, plus development corridors urban growth prediction by city, 2016-2030.

Baseline 2: economic performance vs. scenario 1: development corridors.

The correlation between the Economic Performance Index and the urban growth prediction of each city of different years helps to explain the details of city-level growth patterns. This relationship also reveals finer-grained details of the growth prediction. Here the Economic Performance Index was the x axis and the normalized urban growth outcome was the y axis. Both axes were scaled to values between zero and one. The graphs were divided into four quadrants. The upper right, or quadrant one, represented the high economic performance and high urban growth, whereas the lower left, or quadrant three, was for the low economic performance and low urban growth. If a substantial amount of cities were falling into quadrant two, upper left, and/or quadrant four, lower right, then these cities need to pay more attention to their development patterns. Either they were growing not fast enough, or their current economic performances outran their urbanization process[3]. However, there were no general conclusions and the situations were highly associated with the local conditions and the urbanization patterns, for example, density, diversity, compactness, and connectivity, which were described as 'Urban Intensity' (Guan & Rowe, 2016).

Results from three selected years were shown for baseline 2: economic performance versus scenario 1: development corridors. Figure 96 shows the results in 2011. Most of the cities were in the first quadrant, with only a few stragglers in the second and fourth quadrant, and no cities in the third quadrant. What these meant was that the cities were growing at the right speed and to the right size according to their economic performances, if the future growth were to be constrained to the development corridors in Changjiang Delta Region. Moving from 2011 to 2020 (Figure 96) and 2030 (Figure 97), there were noticeable changes of cities located along the

[3] There were some cities with only a portion located inside the boundary of the urban growth model. The urban growth number was adjusted using an estimated number in proportion to the areas located outside of the boundary. Thus, the urbanization process was not entirely based on the prediction of the Scenario Cellular Automata model.

development corridors in the region moved further to the right of the graph in quadrant one. On the other hand, the cities located outside of the development corridors, mostly middle-sized cities, moved backward to the left of the graph in quadrant one with no quadrant changes. It showed what the models were intended to do: urbanize the area within the development corridors. The implication behind this also showed a mismatch between economic performance and the extent of urban growth. It was also supported by the R-square fitting of the trend curve that the value of R dropped from 0.1986 in 2011 to 0.1853 in 2020 and then further down to 0.1688 in 2030. In this scenario, the reallocation of capital and financial resources becomes critical to support the region emphasized by the pro-growth policy. Another observation was the 'outliers' in the upper right quadrant number one. These cities included Ningbo[4], Nantong, Taizhou, and a few others. Especially for Ningbo, a well-performing city with a strong growth potential was left behind in its urbanization process, supporting the recent expansion of its administrative boundaries (Personal interview with District Mayor Wu, December 2015). Throughout the predicting years, there were some improvements by way of catching up, but not enough to catch up with other cities of identical economic capacity. The discussion section attempts to provide further comment on outliers like Ningbo.

[4] For Ningbo, the number of urban growth parcels was compensated for the portion located outside of the predicting boundary.

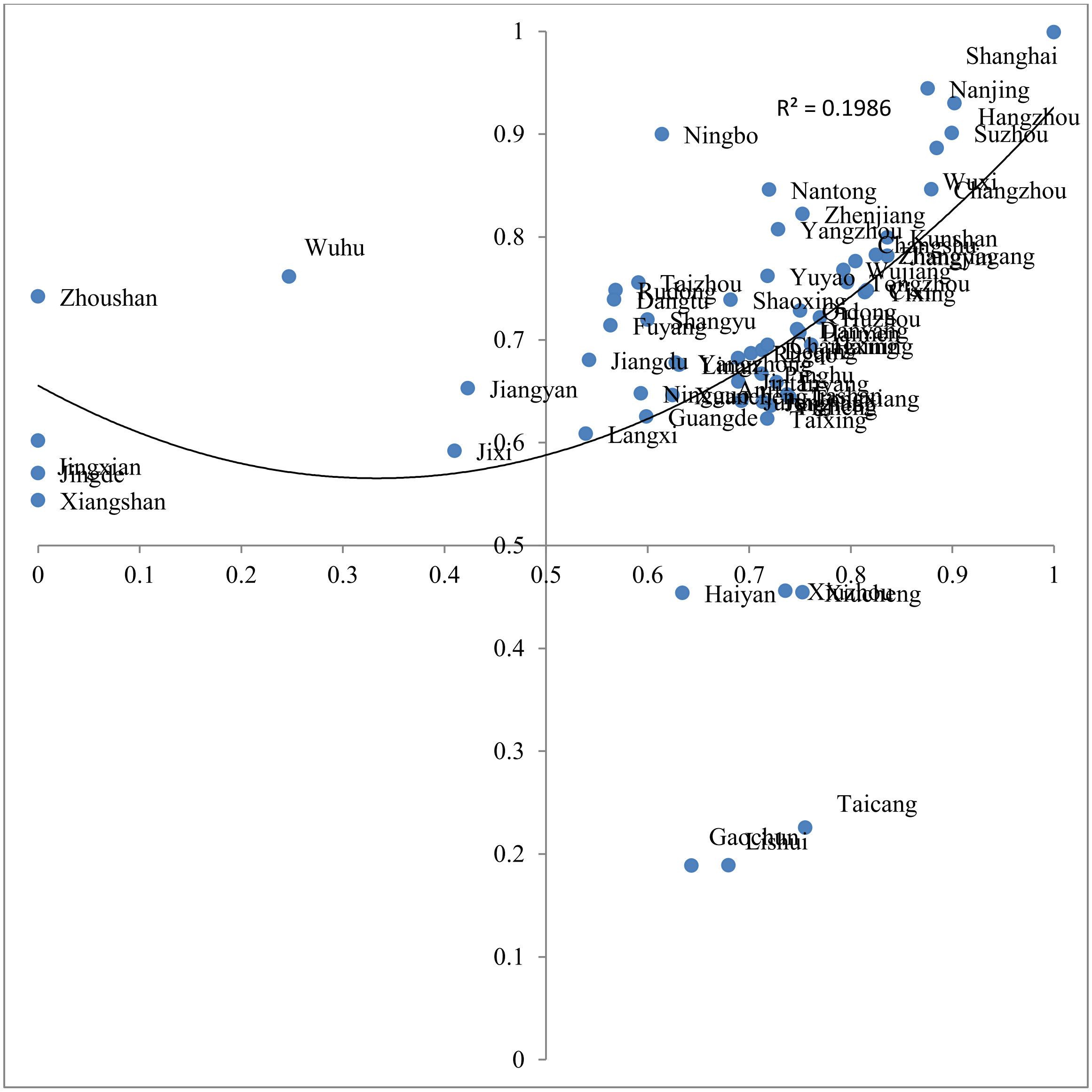


Figure 96. Baseline 2: economic performance vs. scenario 1: development corridors, 2011.

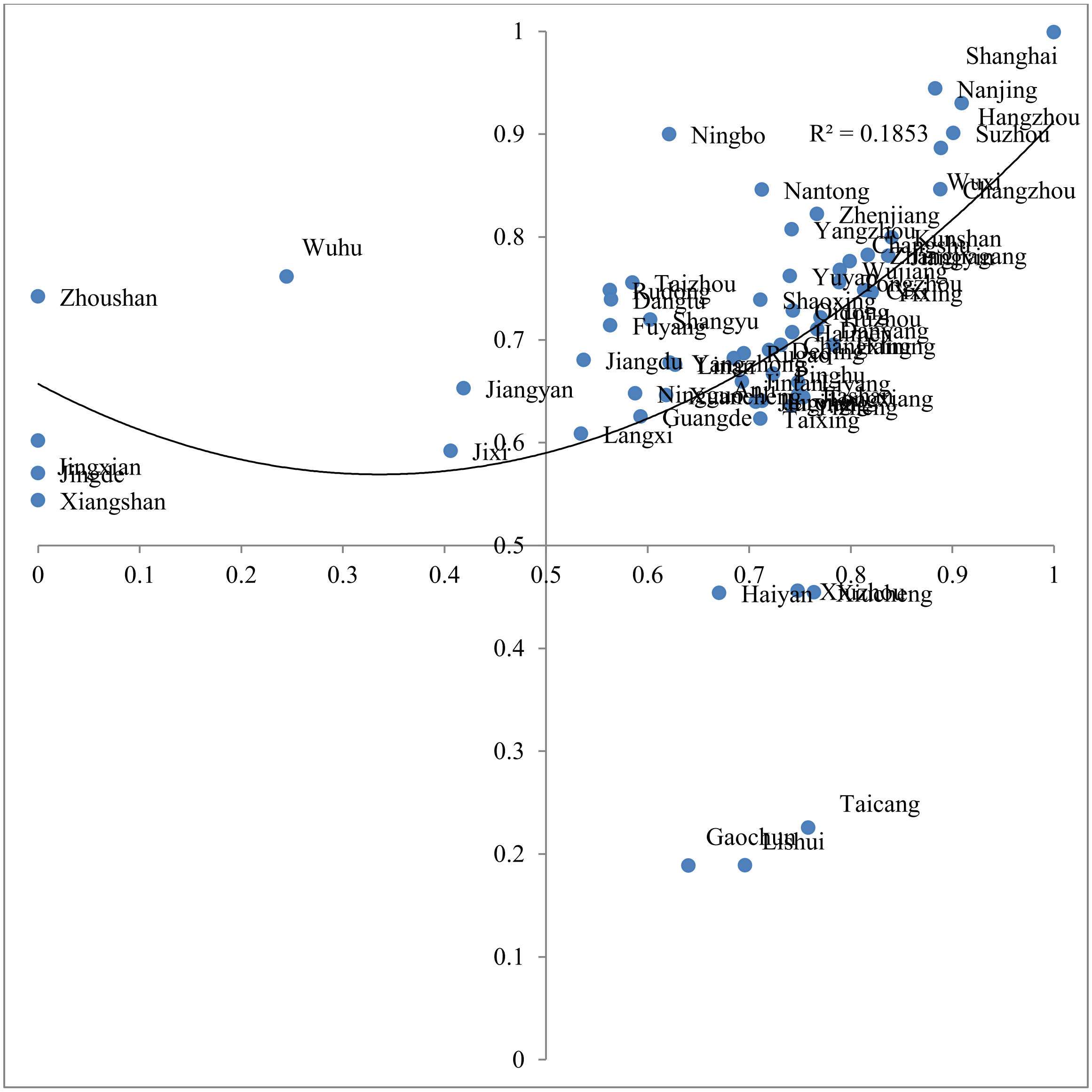


Figure 97. Baseline 2: economic performance vs. scenario 1: development corridors, 2020.

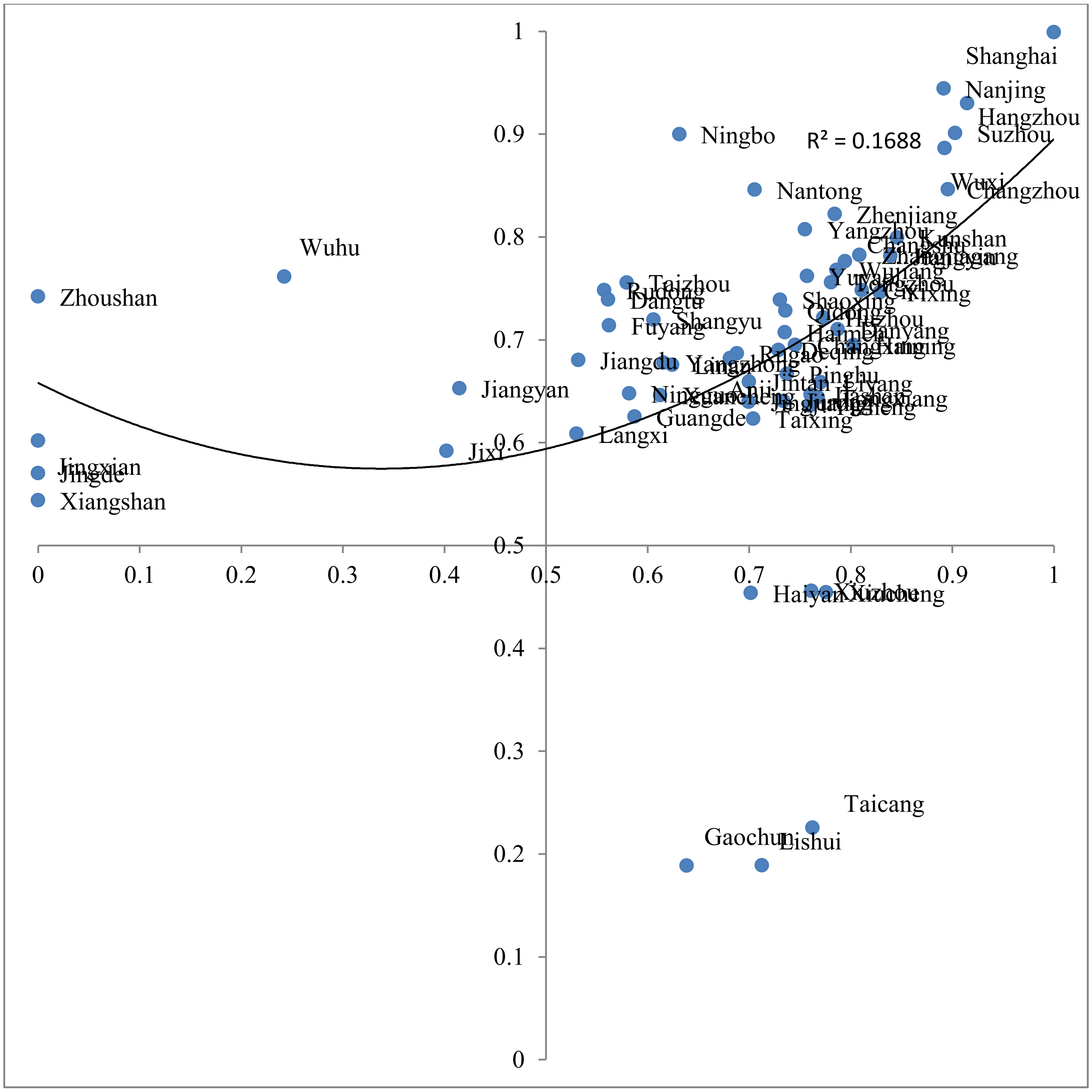


Figure 98. Baseline 2: economic performance vs. scenario 1: development corridors, 2030.

The economic performance and the urban growth data of scenario 1 were then put into Stata, a data analysis and statistical software package for providing pairwise correlation coefficients between variables. Since there was no missing data, the command ‘*pwcorr*’ was applied. Otherwise an alternative command ‘*corr*’ should be used to compensate for incomplete numbers. The results are shown in Table 26.

	var21	*var1*	*var2*	*var3*	*var4*	*var5*	*var6*	*var7*	*var8*	*var9*	*var10*
var21	*1.0000*										
var1	*0.2872*	*1.0000*									
var2	*0.2862*	*1.0000*	*1.0000*								
var3	*0.2851*	*0.9999*	*1.0000*	*1.0000*							
var4	*0.2841*	*0.9999*	*0.9999*	*1.0000*	*1.0000*						
var5	*0.2833*	*0.9998*	*0.9999*	*0.9999*	*1.0000*	*1.0000*					
var6	*0.2824*	*0.9996*	*0.9998*	*0.9999*	*0.9999*	*1.0000*	*1.0000*				
var7	*0.2814*	*0.9995*	*0.9996*	*0.9998*	*0.9999*	*0.9999*	*1.0000*	*1.0000*			
var8	*0.2805*	*0.9993*	*0.9995*	*0.9996*	*0.9998*	*0.9999*	*0.9999*	*1.0000*	*1.0000*		
var9	*0.2795*	*0.9991*	*0.9993*	*0.9995*	*0.9997*	*0.9998*	*0.9999*	*0.9999*	*1.0000*	*1.0000*	
var10	*0.2784*	*0.9989*	*0.9991*	*0.9993*	*0.9995*	*0.9997*	*0.9998*	*0.9999*	*0.9999*	*1.0000*	*1.0000*

	var21	*var11*	*var12*	*var13*	*var14*	*var15*	*var16*	*var17*	*var18*	*var19*	*var20*
var21	*1.0000*										
var11	*0.2776*	*1.0000*									
var12	*0.2766*	*1.0000*	*1.0000*								
var13	*0.2756*	*1.0000*	*1.0000*	*1.0000*							
var14	*0.2746*	*0.9999*	*1.0000*	*1.0000*	*1.0000*						
var15	*0.2737*	*0.9998*	*0.9999*	*1.0000*	*1.0000*	*1.0000*					
var16	*0.2727*	*0.9997*	*0.9998*	*0.9999*	*1.0000*	*1.0000*	*1.0000*				
var17	*0.2718*	*0.9996*	*0.9998*	*0.9998*	*0.9999*	*1.0000*	*1.0000*	*1.0000*			
var18	*0.2708*	*0.9995*	*0.9997*	*0.9998*	*0.9999*	*0.9999*	*1.0000*	*1.0000*	*1.0000*		
var19	*0.2700*	*0.9994*	*0.9995*	*0.9997*	*0.9998*	*0.9999*	*0.9999*	*1.0000*	*1.0000*	*1.0000*	
var20	*0.2691*	*0.9992*	*0.9994*	*0.9996*	*0.9997*	*0.9998*	*0.9999*	*0.9999*	*1.0000*	*1.0000*	*1.0000*

Table 26. Correlation coefficient between economic performance and urban growth prediction from 2011 to 2030. In the table, var21 is economic performance, var1 is 2011, var2 is 2012, and var3 is 2013, and so on. Baseline 2: economic performance vs. scenario 1: development corridors.

The correlation coefficients were projected in a line table, as shown in Figure 99, with a very high 'R square' and descending values. If the line were not smooth, then it was either an error caused by the Scenario Cellular Automata model or there were some dramatic changes of situations along the timeline, for example, topographical conditions. Another possibility was the backward trend of shrinking cities. However, the model didn't have the ability to de-urbanize an urbanized parcel. Further developing of the Scenario Cellular Automata model to include this feature could address issues that many regions are encountering nowadays, such as Detroit in the United States.

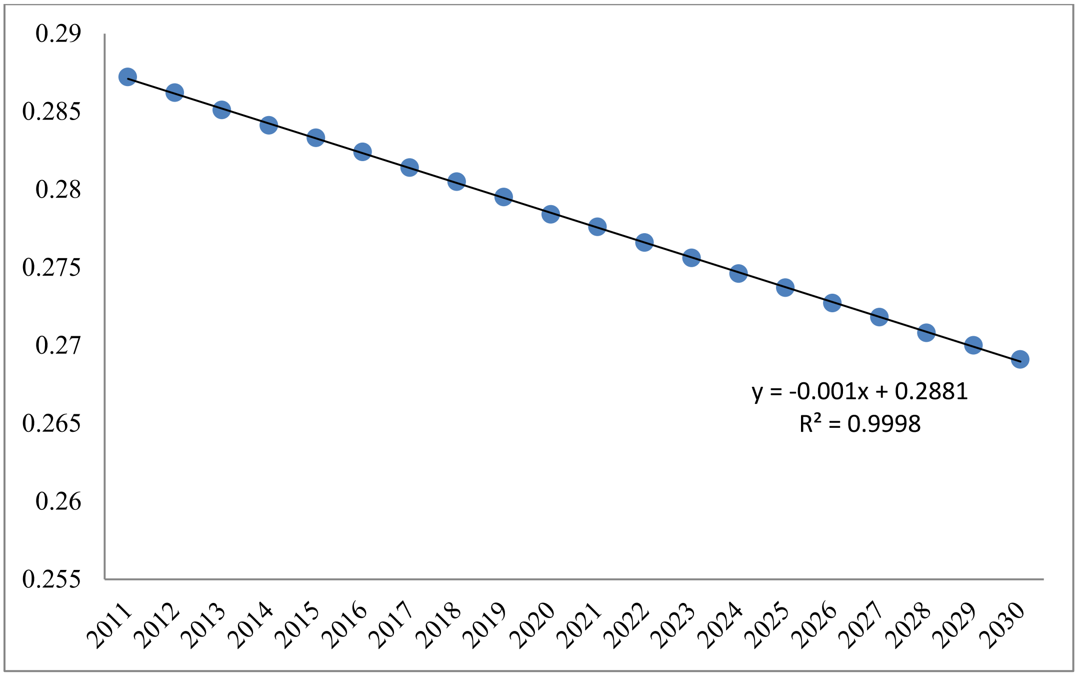


Figure 99. Correlation coefficients projected by years, 2011-2030, baseline 2: economic performance vs. scenario 1: development corridors.

Baseline 2: economic performance vs. scenario 2: development corridors, plus big city growth.

Results from three selected years were shown for baseline 2: economic performances versus scenario 2: development corridors, plus big city growth. The correlation between the Economic Performance Index and the urban growth prediction of each city of different years helps to explain the details of city-level growth patterns. This relationship also revealed finer-grained details of the growth prediction.

Similar to the previous scenario, the graphs were divided into four quadrants. Results from three selected years were shown for baseline 2: economic performance versus scenario 2:

development corridors, plus big city growth. The observations made on distribution patterns, outliers, and general trend are very much identical to scenario 1.

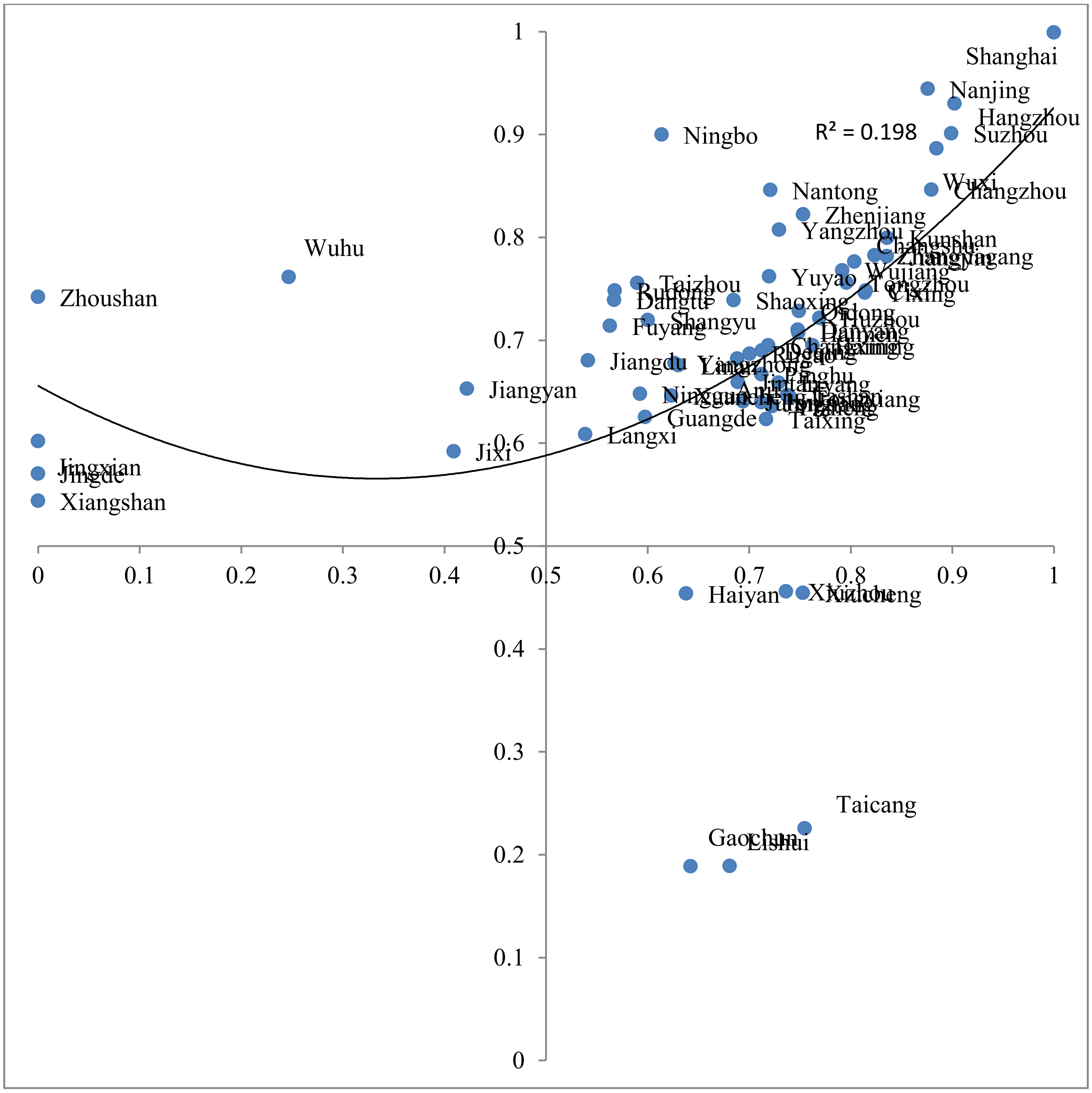


Figure 100. Baseline 2: economic performances versus scenario 2: development corridors, plus big city growth, 2011.

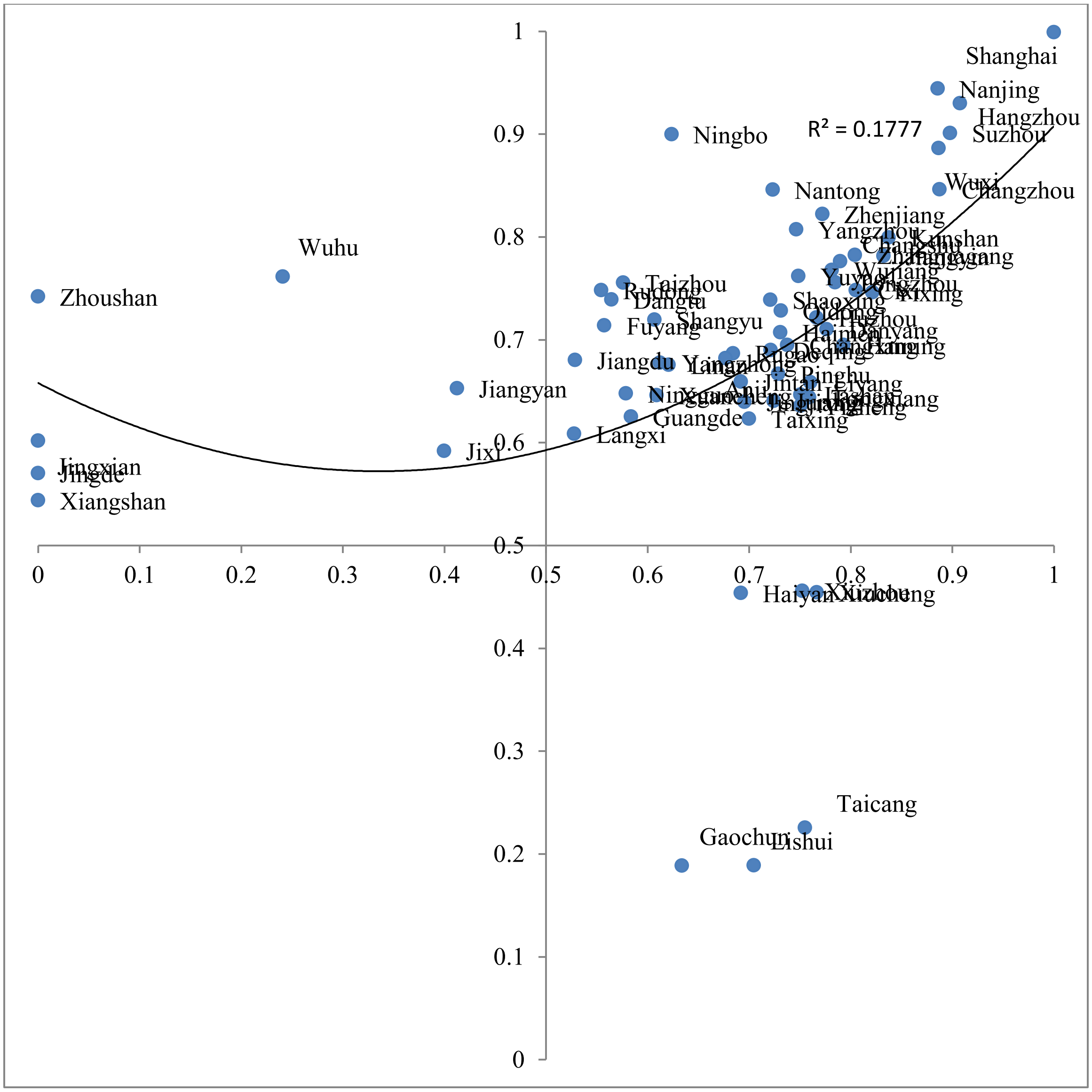


Figure 101. Baseline 2: economic performances versus scenario 2: development corridors, plus big city growth, 2020.

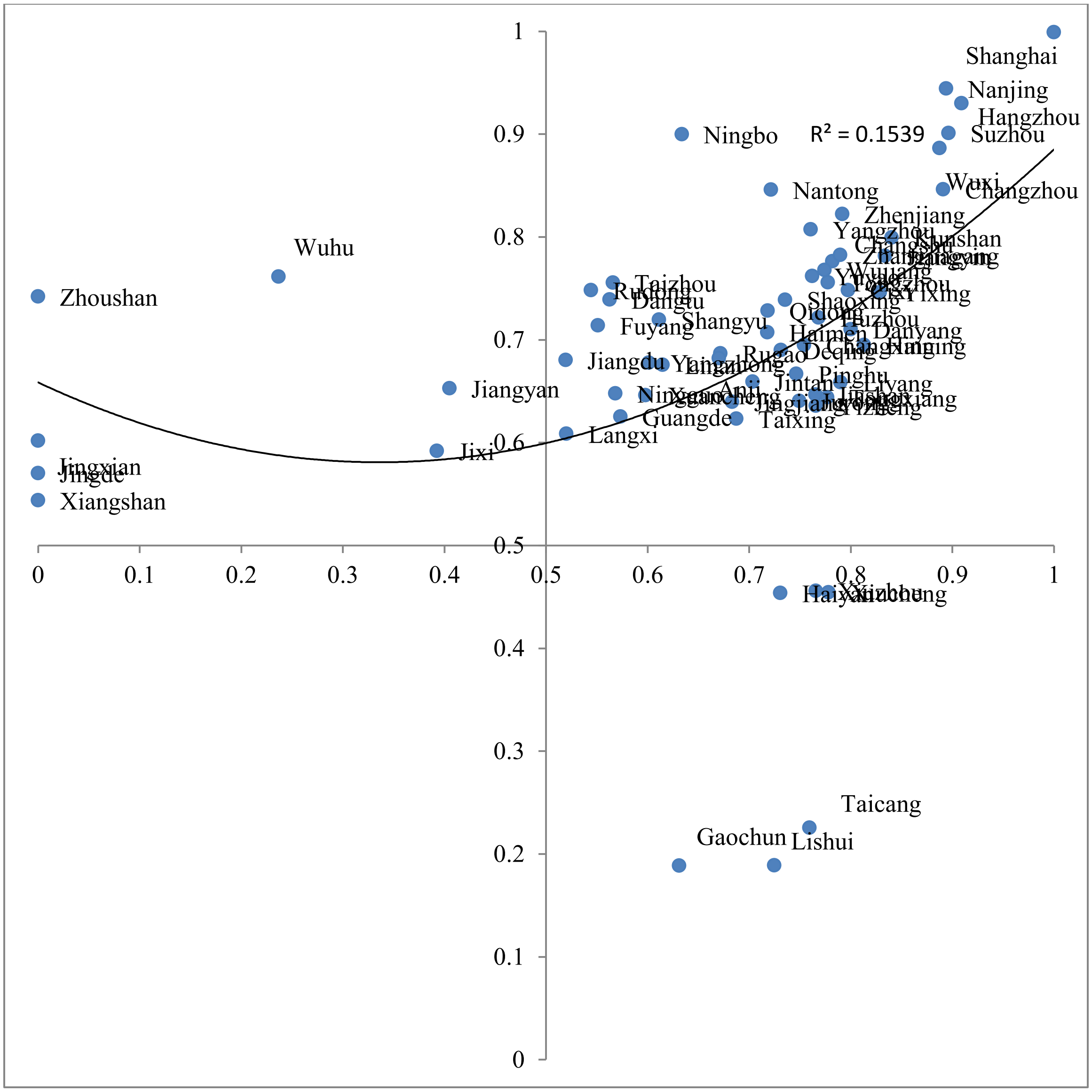


Figure 102. Baseline 2: economic performances versus scenario 2: development corridors, plus big city growth, 2030.

Again, the economic performance and the urban growth data of scenario 1 were then put into Stata to calculate correlation coefficient. The results are reproduced in Table 27. The correlation coefficients were projected in a line table, as shown in Figure 103, with a very high 'R-square' and a descending value.

Table 27. Correlation coefficient between economic performance and urban growth prediction from 2011 to 2030. In the table, var21 is economic performance, var1 is 2011, var2 is 2012, and var3 is 2013, and so on. Baseline 2: economic performances versus scenario 2: development corridors, plus big city growth.

	var21	*var1*	*var2*	*var3*	*var4*	*var5*	*var6*	*var7*	*var8*	*var9*	*var10*
var21	*1.0000*										
var1	*0.2866*	*1.0000*									
var2	*0.2853*	*1.0000*	*1.0000*								
var3	*0.2839*	*0.9998*	*1.0000*	*1.0000*							
var4	*0.2825*	*0.9996*	*0.9998*	*1.0000*	*1.0000*						
var5	*0.2811*	*0.9993*	*0.9996*	*0.9998*	*1.0000*	*1.0000*					
var6	*0.2797*	*0.9989*	*0.9993*	*0.9996*	*0.9998*	*1.0000*	*1.0000*				
var7	*0.2784*	*0.9985*	*0.9990*	*0.9994*	*0.9997*	*0.9999*	*1.0000*	*1.0000*			
var8	*0.2770*	*0.9981*	*0.9987*	*0.9991*	*0.9995*	*0.9997*	*0.9999*	*1.0000*	*1.0000*		
var9	*0.2757*	*0.9976*	*0.9983*	*0.9988*	*0.9992*	*0.9995*	*0.9997*	*0.9999*	*1.0000*	*1.0000*	
var10	*0.2744*	*0.9972*	*0.9978*	*0.9984*	*0.9989*	*0.9993*	*0.9996*	*0.9998*	*0.9999*	*1.0000*	*1.0000*

	var21	*var11*	*var12*	*var13*	*var14*	*var15*	*var16*	*var17*	*var18*	*var19*	*var20*
var21	*1.0000*										
var11	*0.2730*	*1.0000*									
var12	*0.2716*	*1.0000*	*1.0000*								
var13	*0.2702*	*0.9999*	*1.0000*	*1.0000*							
var14	*0.2689*	*0.9998*	*0.9999*	*1.0000*	*1.0000*						
var15	*0.2676*	*0.9997*	*0.9998*	*0.9999*	*1.0000*	*1.0000*					
var16	*0.2663*	*0.9996*	*0.9997*	*0.9999*	*0.9999*	*1.0000*	*1.0000*				
var17	*0.2651*	*0.9994*	*0.9996*	*0.9998*	*0.9999*	*0.9999*	*1.0000*	*1.0000*			
var18	*0.2639*	*0.9992*	*0.9995*	*0.9996*	*0.9998*	*0.9999*	*0.9999*	*1.0000*	*1.0000*		
var19	*0.2626*	*0.9990*	*0.9993*	*0.9995*	*0.9997*	*0.9998*	*0.9999*	*1.0000*	*1.0000*	*1.0000*	
var20	*0.2614*	*0.9988*	*0.9991*	*0.9993*	*0.9995*	*0.9997*	*0.9998*	*0.9999*	*1.0000*	*1.0000*	*1.0000*

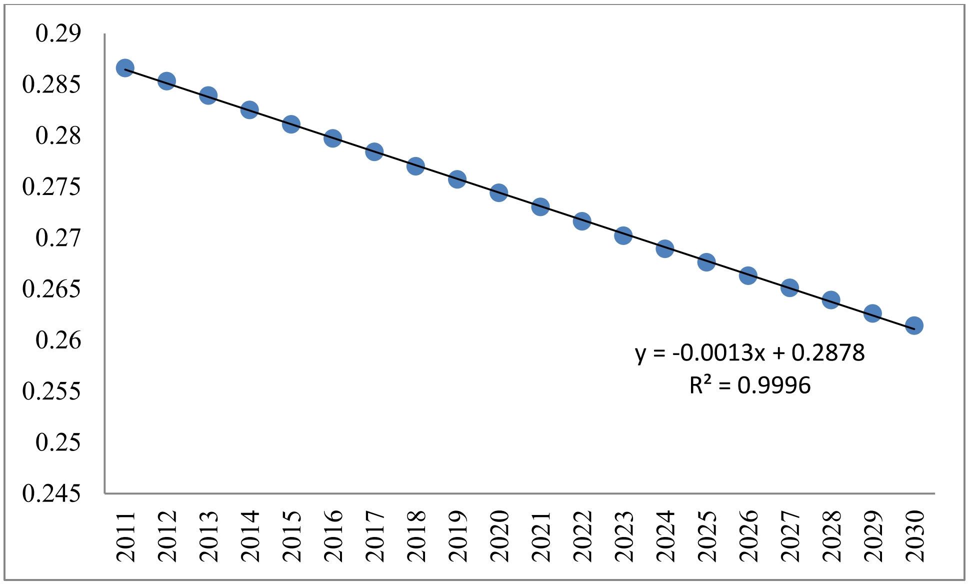


Figure 103. Correlation coefficients projected by year from 2011-2030, baseline 2: economic performances versus scenario 2: development corridors, plus big city growth.

Baseline 2: economic performance vs. scenario 3: ecological system concerns, plus development corridors.

Results from three selected years were shown in figures 104, 105, and 106, for baseline 2: economic performances versus scenario 3: ecological system concerns (forest protection), plus development corridors. Similar to the previous cases, the majority of the cities were located in upper right quadrant number one. Tier 1 cities, by visual observation only, appeared to be Shanghai, Nanjing, Hangzhou, Suzhou, Wuxi, and Changzhou by urbanized land parcel. Outliers appeared to be Ningbo, again, in quadrant one. The cities fell in quadrant two and four were considered error in data collection and normalization processes.

The temporal parameter throughout the prediction years revealed a slight drop of R-square value, or, the explanation power of the dataset. Obviously, the closer to the start year of 2010 the more accurate economic performance data are. However, this is also an opportunity to provide advices and suggestions on the future economic performance pattern at the regional scale.

Mainly, some of the tier two and tier three cities and towns should increase their economic performances at a faster rate than the big cities.

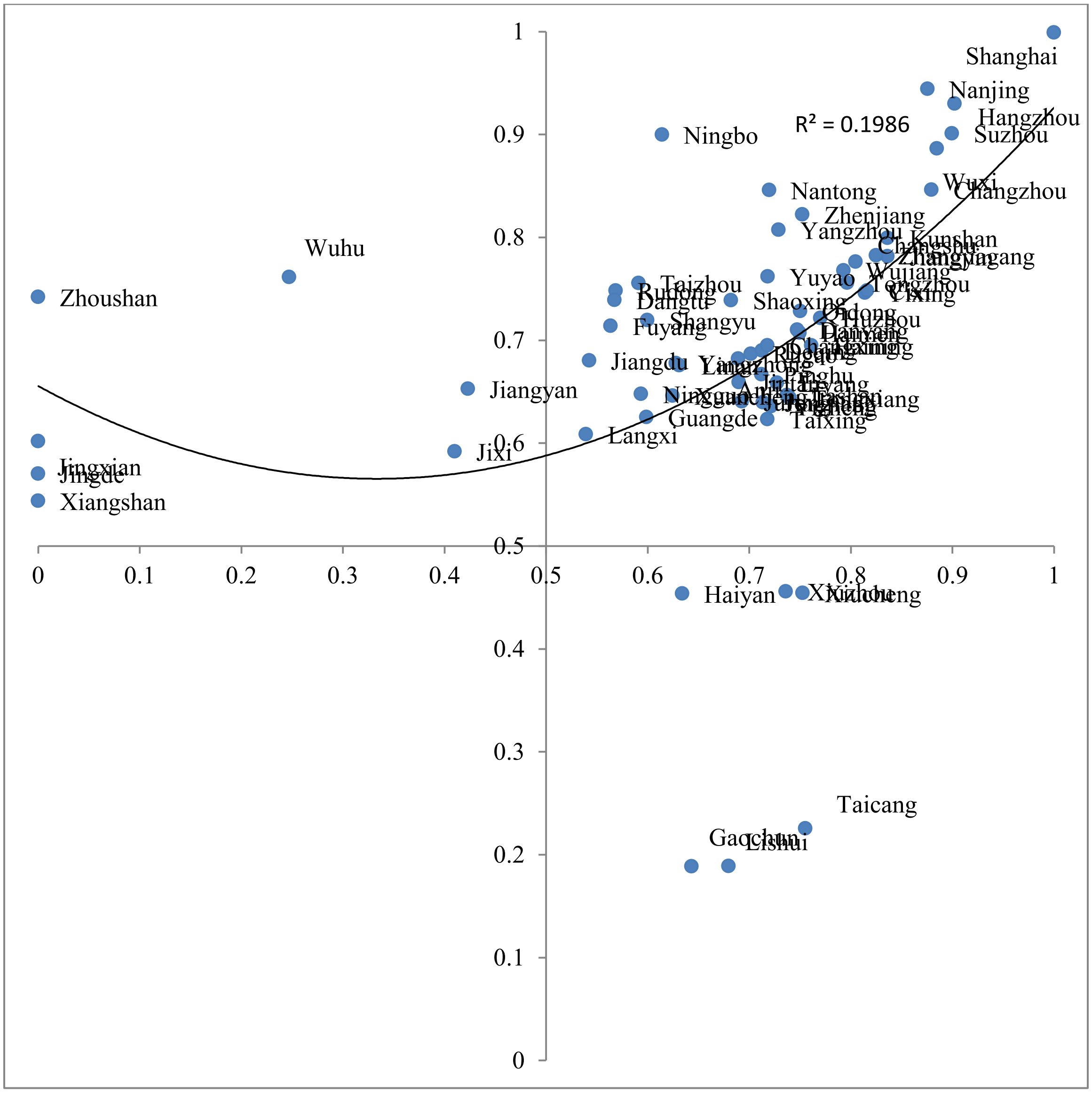


Figure 104. Baseline 2: economic performance vs. scenario 3: ecological system concerns, plus development corridors, 2011.

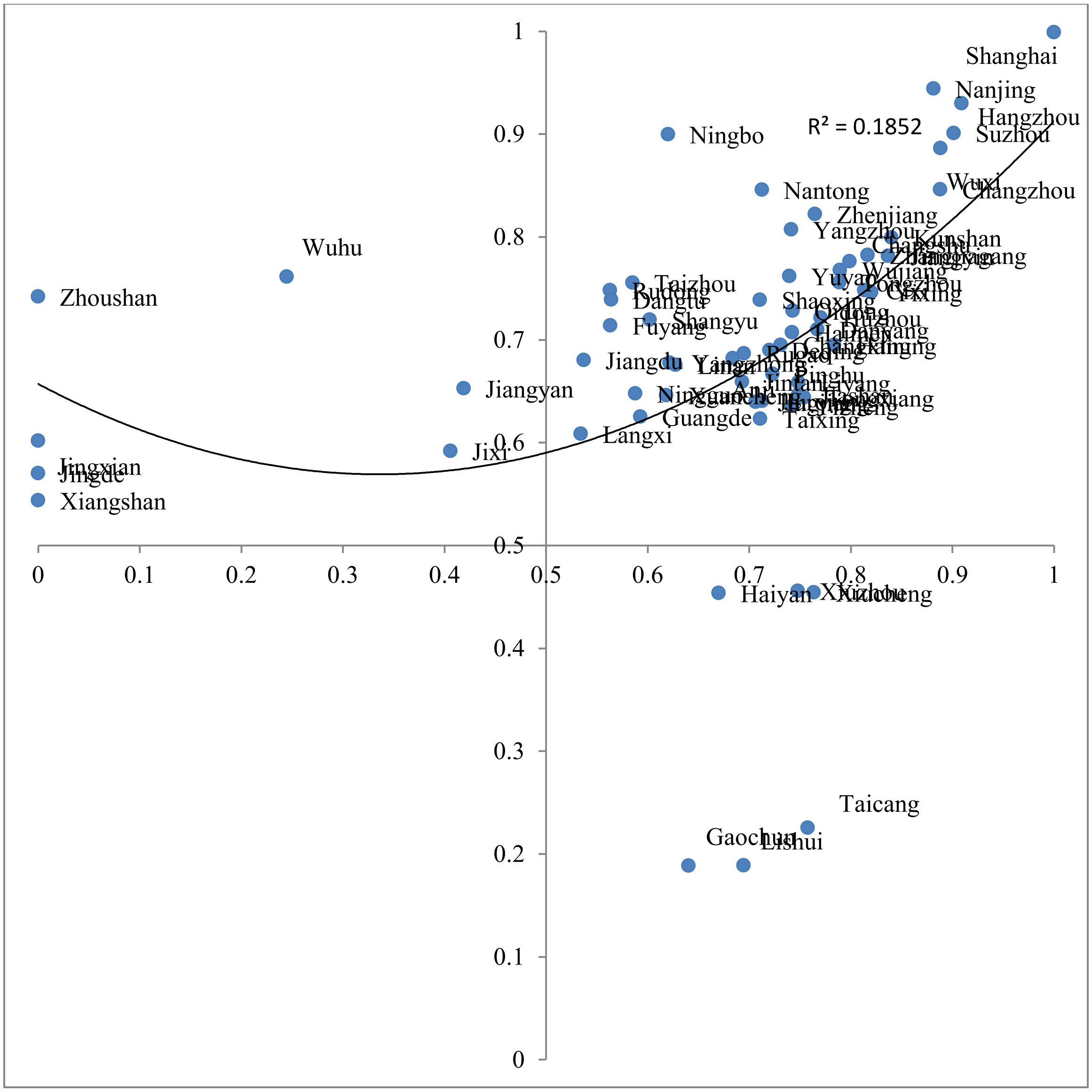


Figure 105. Baseline 2: economic performance vs. scenario 3: ecological system concerns, plus development corridors, 2020.

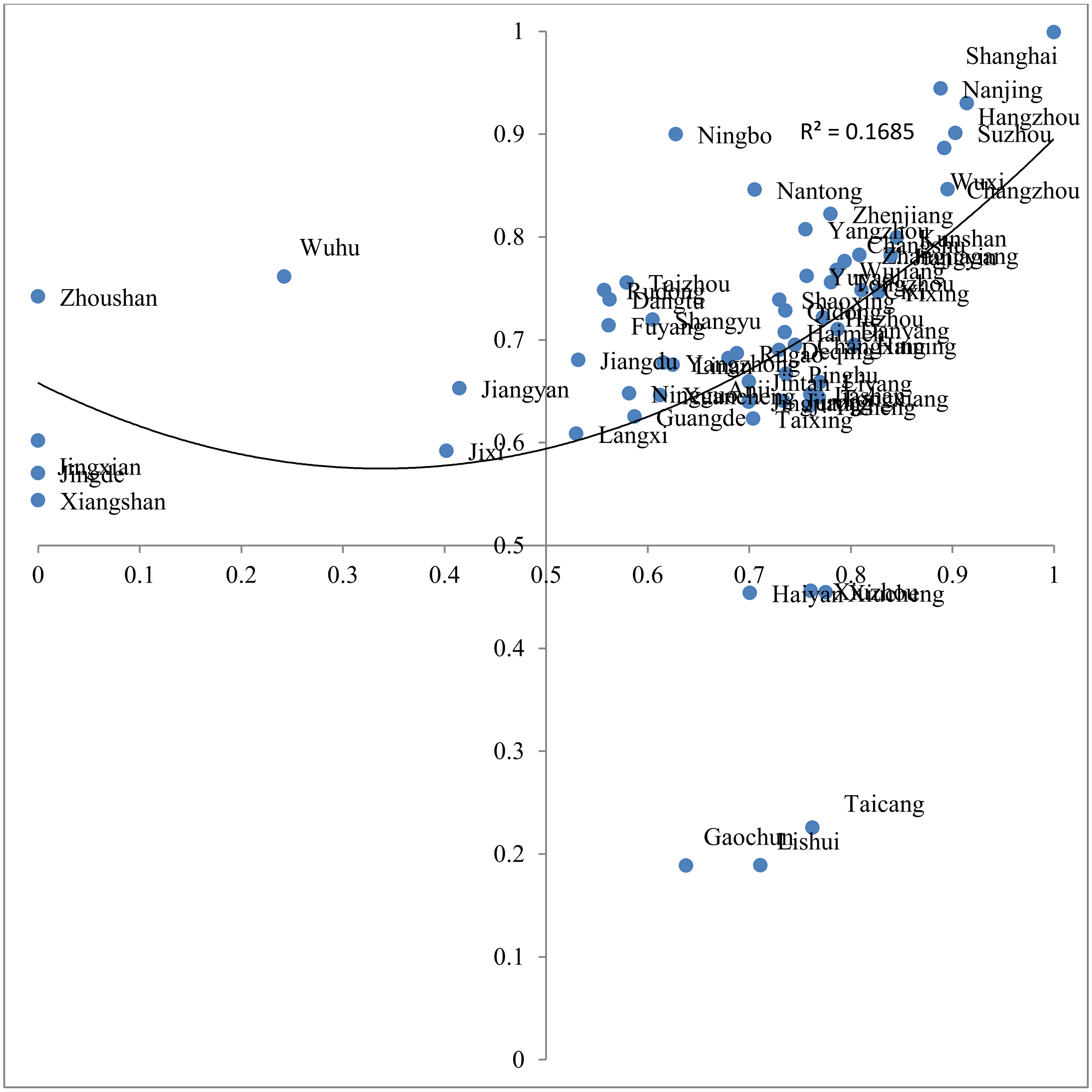


Figure 106. Baseline 2: economic performance vs. scenario 3: ecological system concerns, plus development corridors, 2030.

Again, the economic performance and the urban growth data of scenario 3 were put into Stata to calculate correlation coefficient. The results are reproduced here:

Table 28. Correlation coefficient between economic performance and urban growth prediction from 2011 to 2030. In the table, var21 is economic performance, var1 is 2011, var2 is 2012, and var3 is 2013, and so on. Baseline 2: economic performance vs. scenario 3: ecological system concerns, plus development corridors.

	var21	*var1*	*var2*	*var3*	*var4*	*var5*	*var6*	*var7*	*var8*	*var9*	*var10*
var21	*1.0000*										
var1	*0.2871*	*1.0000*									
var2	*0.2861*	*1.0000*	*1.0000*								
var3	*0.2853*	*0.9999*	*1.0000*	*1.0000*							
var4	*0.2842*	*0.9999*	*0.9999*	*1.0000*	*1.0000*						
var5	*0.2833*	*0.9998*	*0.9999*	*0.9999*	*1.0000*	*1.0000*					
var6	*0.2823*	*0.9996*	*0.9998*	*0.9999*	*0.9999*	*1.0000*	*1.0000*				
var7	*0.2813*	*0.9995*	*0.9996*	*0.9998*	*0.9999*	*0.9999*	*1.0000*	*1.0000*			
var8	*0.2803*	*0.9993*	*0.9995*	*0.9997*	*0.9998*	*0.9999*	*0.9999*	*1.0000*	*1.0000*		
var9	*0.2793*	*0.9991*	*0.9993*	*0.9995*	*0.9997*	*0.9998*	*0.9999*	*0.9999*	*1.0000*	*1.0000*	
var10	*0.2784*	*0.9989*	*0.9991*	*0.9993*	*0.9995*	*0.9997*	*0.9998*	*0.9999*	*1.0000*	*1.0000*	*1.0000*

	var21	*var11*	*var12*	*var13*	*var14*	*var15*	*var16*	*var17*	*var18*	*var19*	*var20*
var21	*1.0000*										
var11	*0.2774*	*1.0000*									
var12	*0.2765*	*1.0000*	*1.0000*								
var13	*0.2755*	*1.0000*	*1.0000*	*1.0000*							
var14	*0.2746*	*0.9999*	*1.0000*	*1.0000*	*1.0000*						
var15	*0.2736*	*0.9998*	*0.9999*	*1.0000*	*1.0000*	*1.0000*					
var16	*0.2727*	*0.9998*	*0.9998*	*0.9999*	*1.0000*	*1.0000*	*1.0000*				
var17	*0.2718*	*0.9997*	*0.9998*	*0.9999*	*0.9999*	*1.0000*	*1.0000*	*1.0000*			
var18	*0.2708*	*0.9995*	*0.9997*	*0.9998*	*0.9999*	*0.9999*	*1.0000*	*1.0000*	*1.0000*		
var19	*0.2698*	*0.9994*	*0.9996*	*0.9997*	*0.9998*	*0.9999*	*0.9999*	*1.0000*	*1.0000*	*1.0000*	
var20	*0.2689*	*0.9993*	*0.9994*	*0.9996*	*0.9997*	*0.9998*	*0.9999*	*0.9999*	*1.0000*	*1.0000*	*1.0000*

The correlation coefficients were once again projected a line table, as shown in Figure 107, with a very high R-square and descending values.

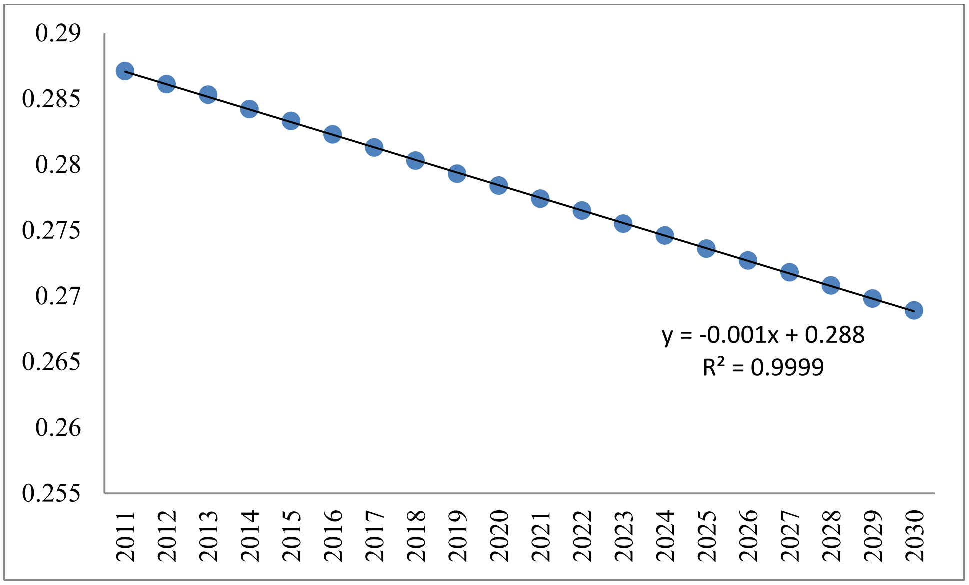


Figure 107. Correlation coefficients projected by year, 2011-2030, baseline 2: economic performance vs. scenario 3: ecological system concerns, plus development corridors.

Baseline 2: economic performance vs. scenario 4: disaster preventions, plus development corridors.

Results from three selected years are shown for baseline 2: economic performances versus scenario 4: disaster preventions, plus development corridors. Similar to the previous cases, the majority of the cities were located in upper right quadrant number one. Tier one cities, by visual observation only, appeared to be Shanghai, Nanjing, Hangzhou, Suzhou, Wuxi, and Changzhou by urbanized land parcel. Outliers appeared to be Ningbo, once again, in quadrant one. The cities fell in quadrant two and four were considered error in data collection and normalization processes.

The temporal parameter throughout the prediction years revealed a slight drop of R-square value, or, the explanation power of the dataset. Obviously, again, the closer to the start year of 2010 the more accurate the economic performance data are. However, as before, this is also an opportunity to provide advice and suggestion on the future economic performance patterns at the regional scale. Again, some of the tier two and tier three cities and towns should increase their economic performances at a faster rate than the big cities.

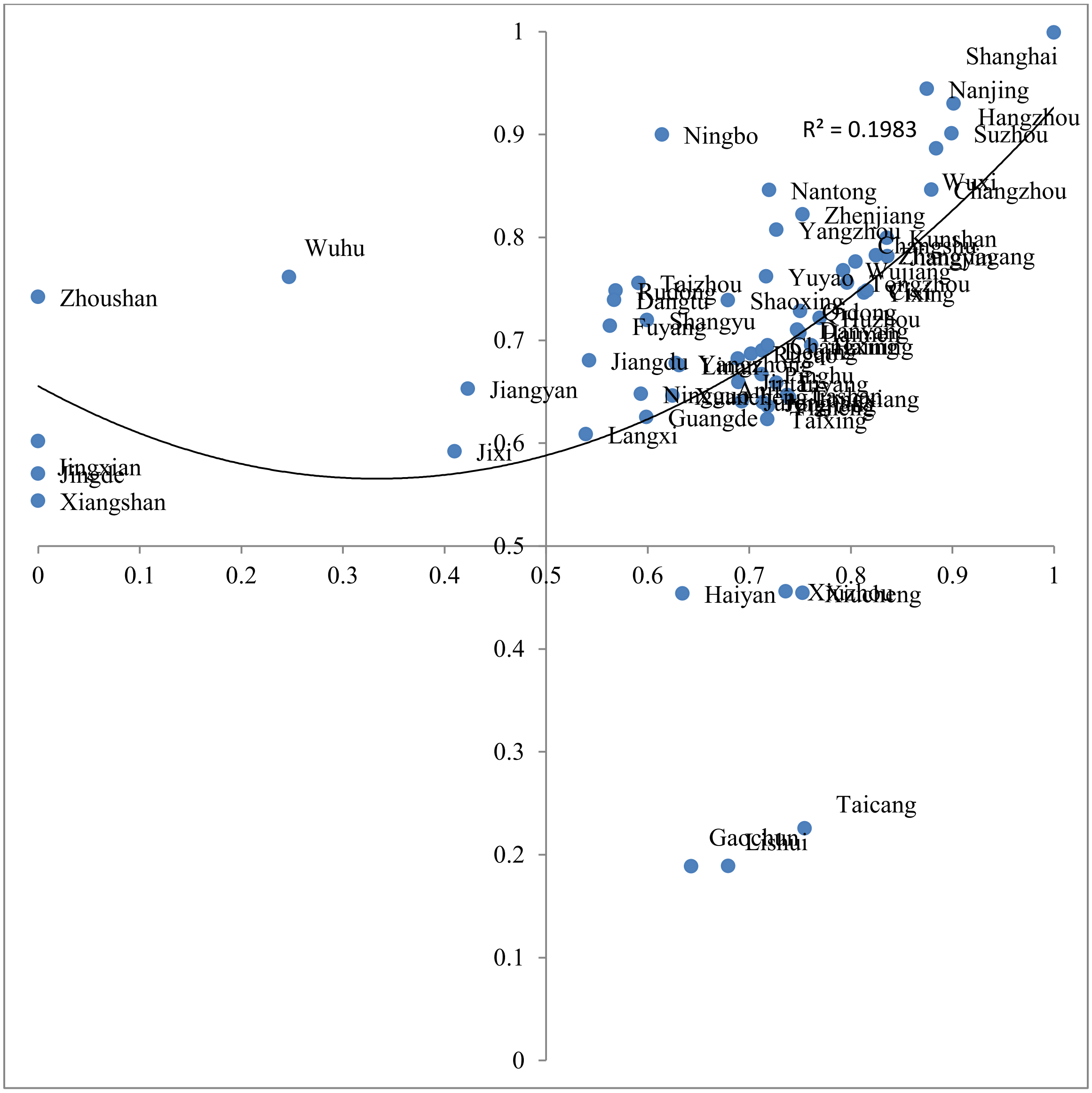


Figure 108. Baseline 2: economic performance vs. scenario 4: disaster prevention, plus development corridors, 2011.

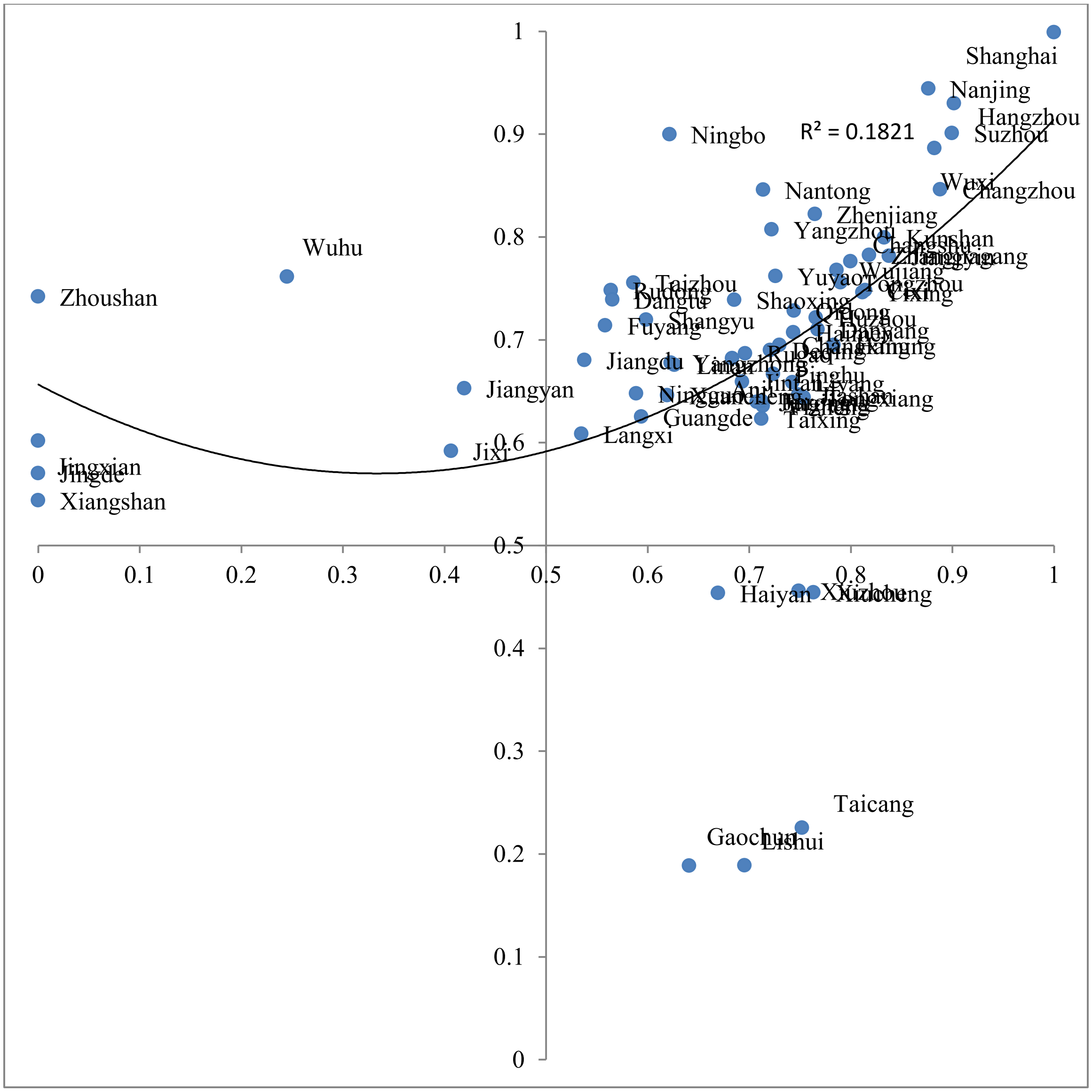


Figure 109. Baseline 2: economic performance vs. scenario 4: disaster prevention, plus development corridors, 2020.

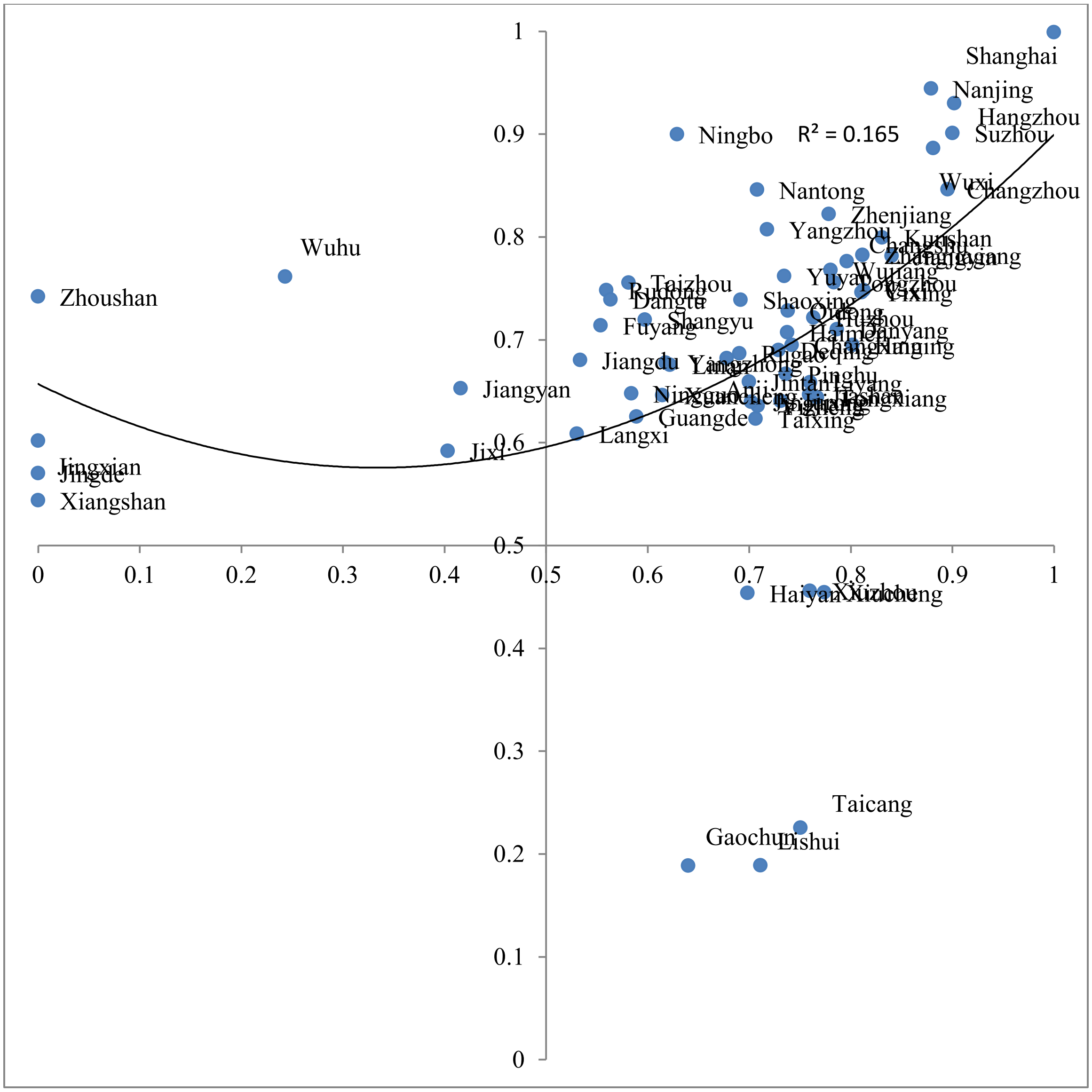


Figure 110. Baseline 2: economic performance vs. scenario 4: disaster prevention, plus development corridors, 2030.

Again, as before, the economic performance and the urban growth data of scenario 4 were put into Stata to calculate correlation coefficient. The results are reproduced here:

Table 29. Correlation coefficient between economic performance and urban growth prediction from 2011 to 2030. In the table, var21 is economic performance, var1 is 2011, var2 is 2012, and var3 is 2013, and so on. Baseline 2: economic performance vs. scenario 4: disaster prevention, plus development corridors.

	var21	*var1*	*var2*	*var3*	*var4*	*var5*	*var6*	*var7*	*var8*	*var9*	*var10*
var21	*1.0000*										
var1	*0.2870*	*1.0000*									
var2	*0.2857*	*1.0000*	*1.0000*								
var3	*0.2845*	*1.0000*	*1.0000*	*1.0000*							
var4	*0.2833*	*0.9999*	*1.0000*	*1.0000*	*1.0000*						
var5	*0.2821*	*0.9998*	*0.9999*	*1.0000*	*1.0000*	*1.0000*					
var6	*0.2811*	*0.9997*	*0.9998*	*0.9999*	*1.0000*	*1.0000*	*1.0000*				
var7	*0.2799*	*0.9996*	*0.9997*	*0.9998*	*0.9999*	*1.0000*	*1.0000*	*1.0000*			
var8	*0.2788*	*0.9995*	*0.9996*	*0.9997*	*0.9998*	*0.9999*	*1.0000*	*1.0000*	*1.0000*		
var9	*0.2776*	*0.9993*	*0.9995*	*0.9996*	*0.9997*	*0.9998*	*0.9999*	*1.0000*	*1.0000*	*1.0000*	
var10	*0.2765*	*0.9991*	*0.9993*	*0.9995*	*0.9996*	*0.9997*	*0.9998*	*0.9999*	*1.0000*	*1.0000*	*1.0000*

	var21	*var11*	*var12*	*var13*	*var14*	*var15*	*var16*	*var17*	*var18*	*var19*	*var20*
var21	*1.0000*										
var11	*0.2754*	*1.0000*									
var12	*0.2744*	*1.0000*	*1.0000*								
var13	*0.2734*	*1.0000*	*1.0000*	*1.0000*							
var14	*0.2723*	*0.9999*	*1.0000*	*1.0000*	*1.0000*						
var15	*0.2712*	*0.9999*	*0.9999*	*1.0000*	*1.0000*	*1.0000*					
var16	*0.2702*	*0.9998*	*0.9999*	*0.9999*	*1.0000*	*1.0000*	*1.0000*				
var17	*0.2692*	*0.9997*	*0.9998*	*0.9999*	*0.9999*	*1.0000*	*1.0000*	*1.0000*			
var18	*0.2683*	*0.9996*	*0.9997*	*0.9998*	*0.9999*	*0.9999*	*1.0000*	*1.0000*	*1.0000*		
var19	*0.2672*	*0.9995*	*0.9996*	*0.9997*	*0.9998*	*0.9999*	*0.9999*	*1.0000*	*1.0000*	*1.0000*	
var20	*0.2663*	*0.9994*	*0.9996*	*0.9997*	*0.9998*	*0.9998*	*0.9999*	*0.9999*	*1.0000*	*1.0000*	*1.0000*

Once again, the correlation coefficients were projected a line table, as shown in Figure 111, with a very high 'R-square' followed by descending values.

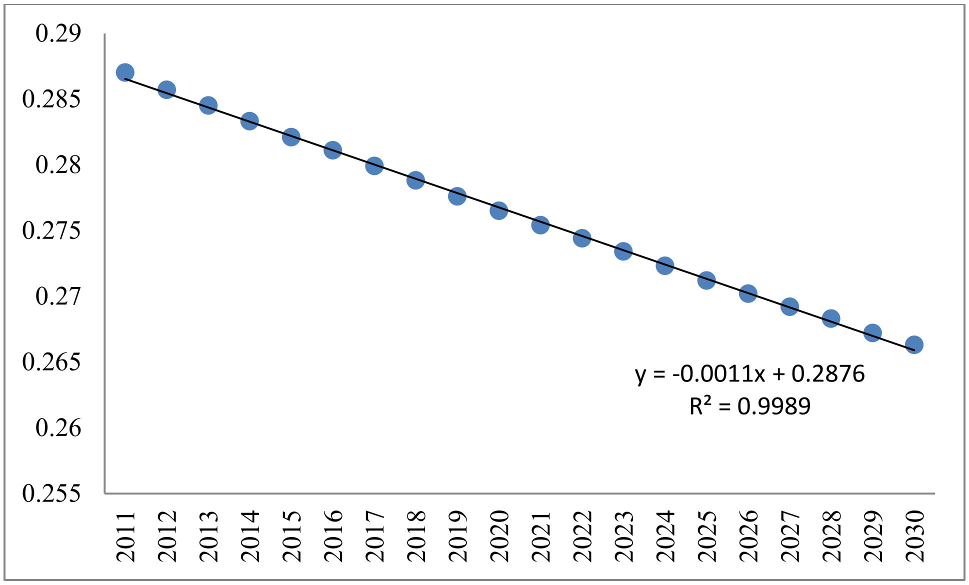


Figure 111. Correlation coefficients projected by years, 2011-2030, baseline 2: economic performance vs. scenario 4: disaster prevention, plus development corridors.

c. Baseline 3 Cultural amenities and the projections of the four selected scenarios

Cultural Amenity Index

As discussed in early chapters, the Changjiang Delta Region was defined as a network of cities and towns connected within a physical boundary. The total number of cities and towns under consideration here was 62. The information for the cultural amenity index of these 62 cities and towns was collected, as noted earlier, included public green recreational green space, numbers of parks, and urban landscape and park areas. These figures were then brought to Excel and Stata for data processing and normalization. For the area of public recreational green space and urban landscape park area, both units were in hectares, the normalization used natural logarithms to eliminate outliers and then the logarithmic numbers were scaled between zero and one. The ranking of normalized 'recreational green space' was then plotted through a scatter chart in Figure 112. For number of parks, the normalization applied to the distribution and standard deviation method. The ranking was plotted to Figure 113. The park area ranking was shown in Figure 114.

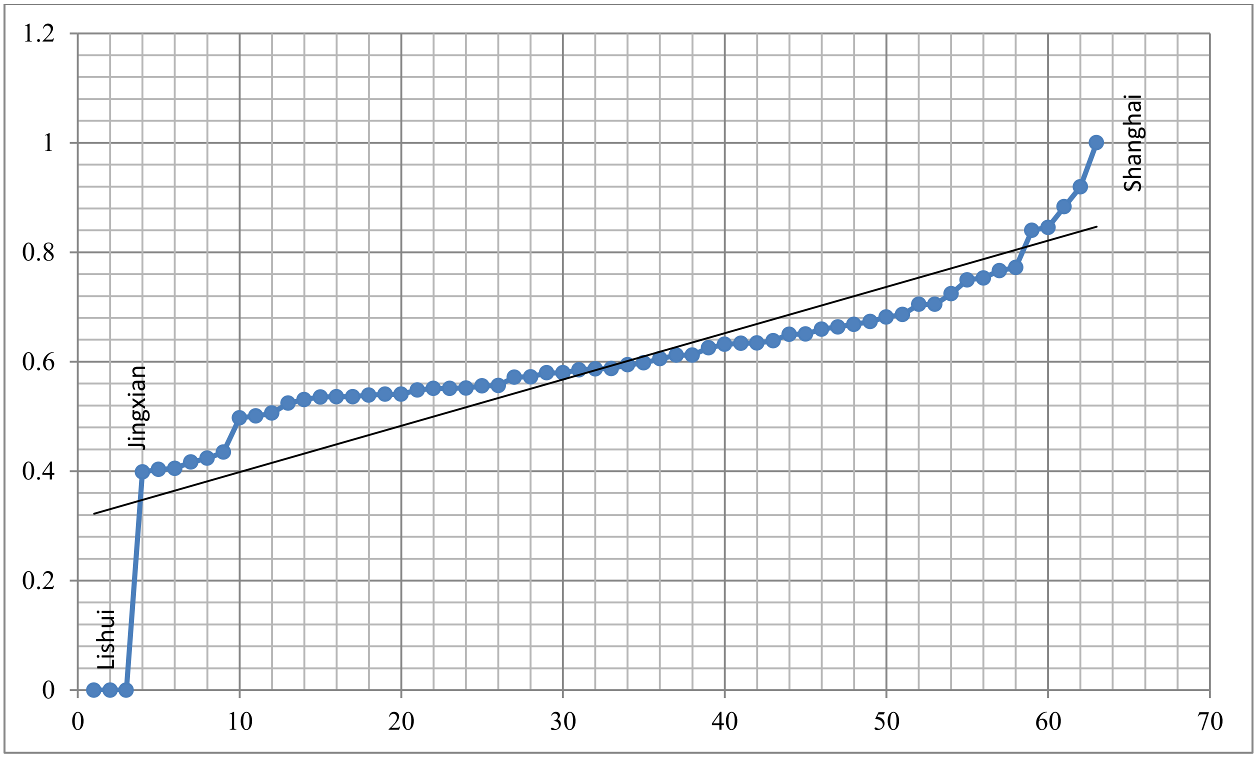


Figure 112. Public recreational green space ranking, 2010.

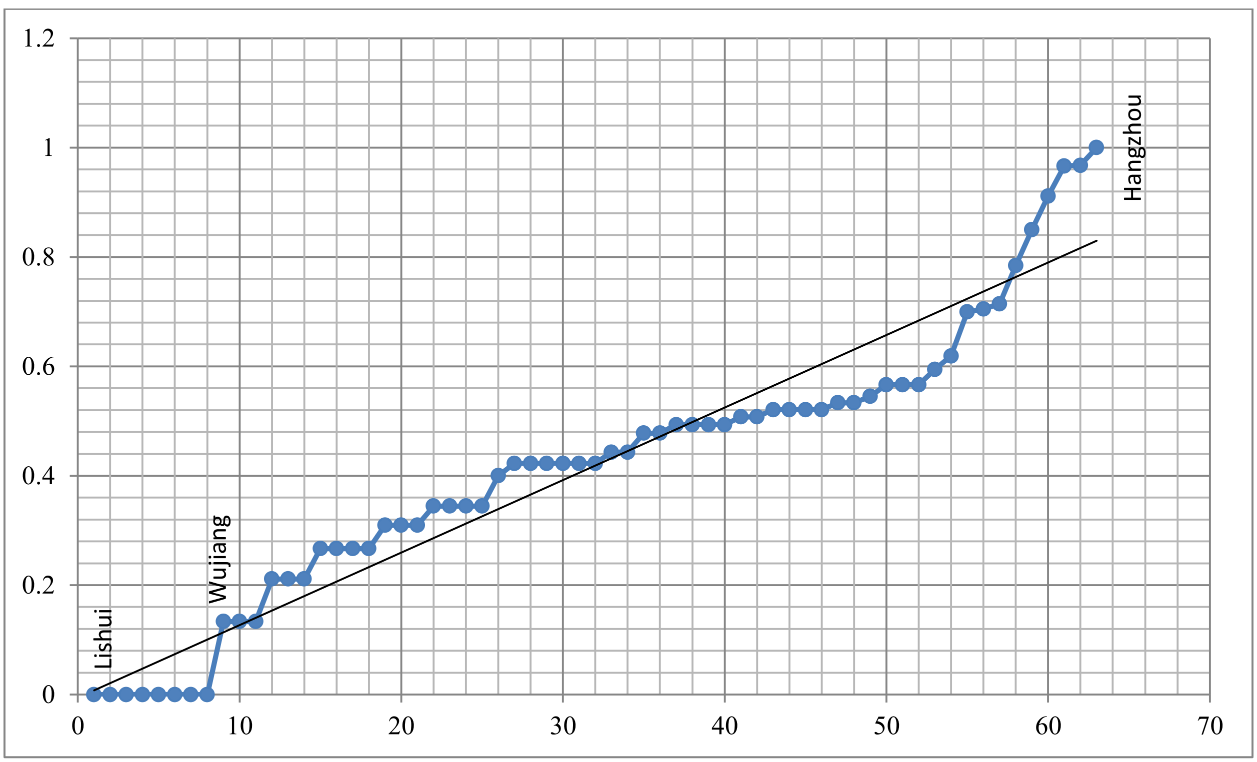


Figure 113. Number of parks ranking, 2010.

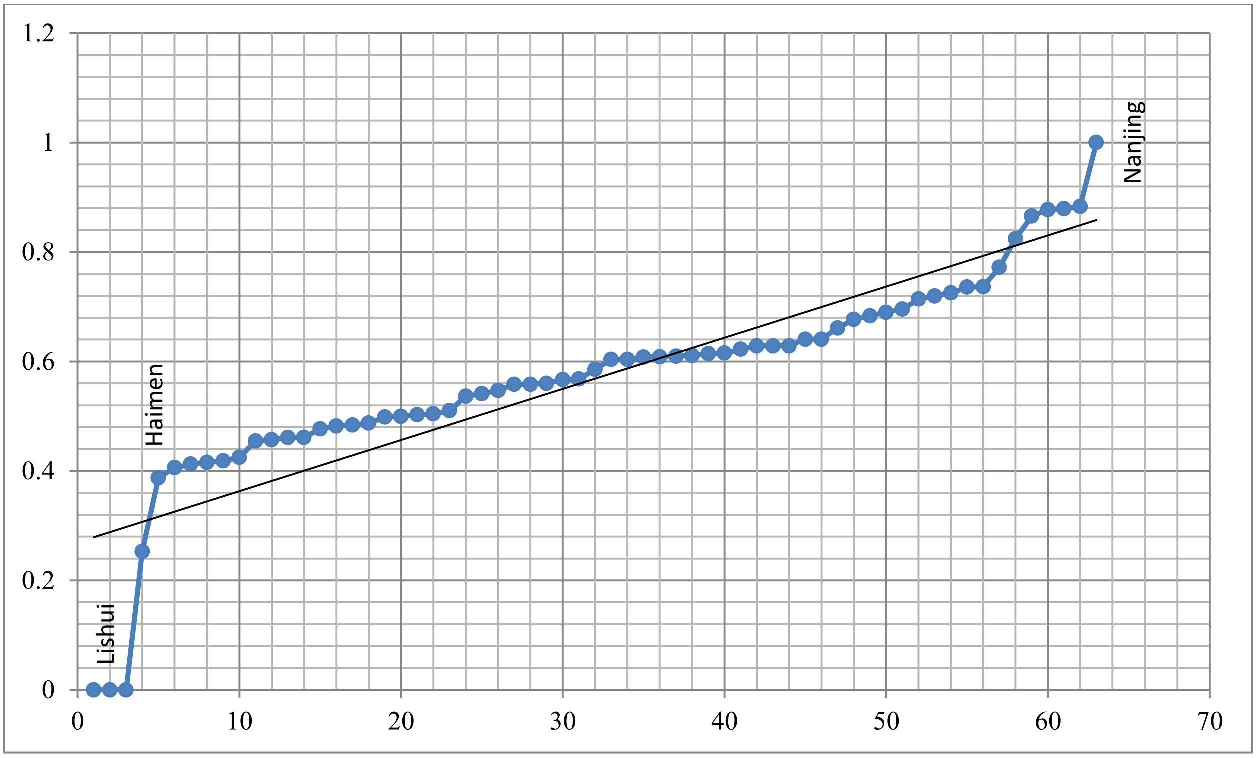


Figure 114. Urban landscape and park areas ranking, 2010.

The next step was to study the correlation between the number of parks and the park areas. The raw data of 'urban landscape and park areas' and 'number of parks' were imported to statistical analysis software Stata. In Stata, the command '*corr*' was applied to discover the relationship between the two variables. The results showed that among the 62 observations, the correlation coefficient was 0.6543. This number revealed that the 'urban landscape and park area' and 'number of parks' were positively correlated. Not unexpectedly, it was clear that the more parks the more area of urban landscape. However, individual parks did vary in size evidently in some cities, such as Nanjing, which possessed the most park area, but only had 83 parks. In effect parks were more than twice in size, over 5,200 hectares, but only half of the number when comparing with some other cities such as Suzhou, Zhenjiang, and Ningbo. This demonstrated that the park area and park number together revealed the distribution of parks. The two variables defined the characteristics of parks in terms of distribution, compactness, and density. These are all relevant factors of spatial distribution of cultural amenities. In conclusion, both were kept as important variables. Thus, a reduced weight of 0.5 was given to the number of parks to reduce the overall impact of park related variables.

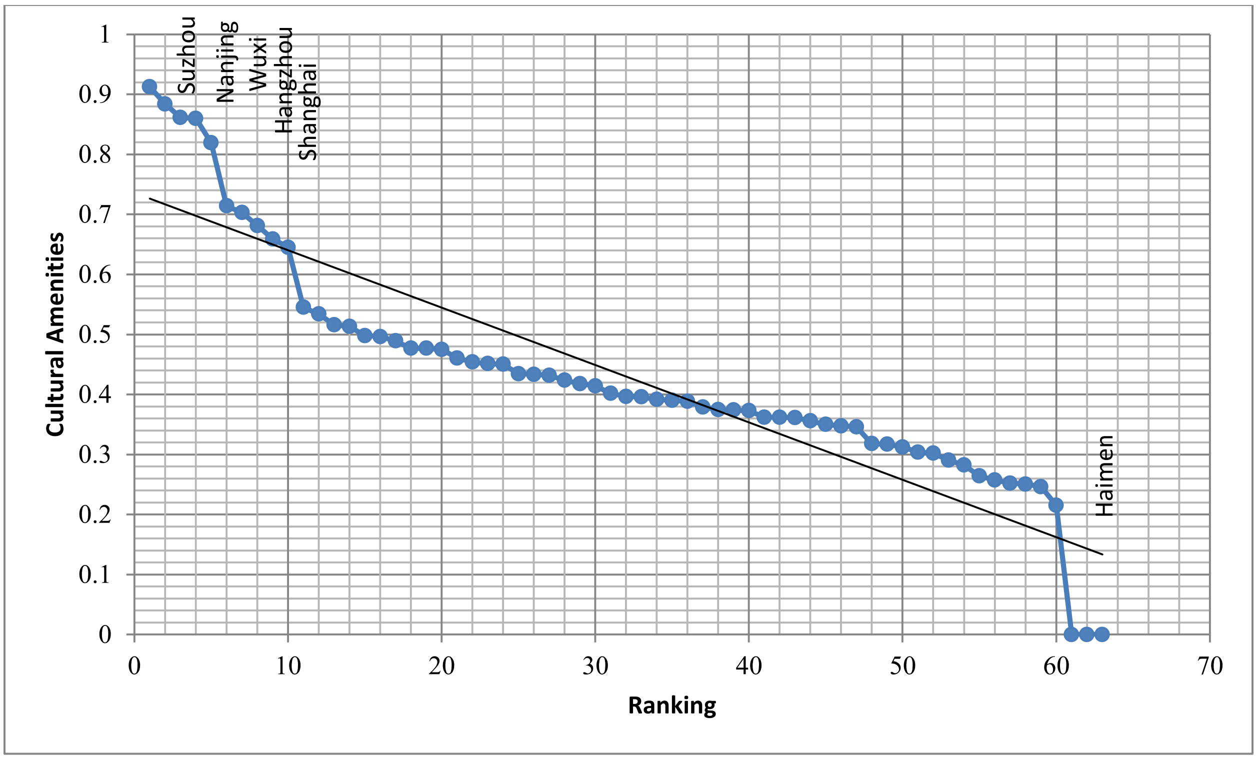


Figure 115. Cultural amenity scores and ranking, 2010.

Urban growth predictions at city-level

The results of city-level urban growth prediction are reproduced earlier in Figures 84, 85, and 86. As stated before, they showed the urban growth prediction outcomes from scenario 1: development corridors by city from 2016 to 2030. Tables 14, 15, and 16 shows data collection processes using natural logarithms and normalization.

The correlation between the cultural amenity index and the urban growth prediction of each city of different years explained the details of city-level growth patterns. This relationship also revealed finer-grain details of the growth prediction.

i. Baseline 3: cultural amenities vs. scenario 1: development corridors

Figures 116, 117, and 118 show the correlation between the Cultural Amenity Index and the urban growth predicted by scenario 1: development corridors. The x axis is the cultural amenity index and the y axis is the urban growth prediction. In the top right corner, in all three figures, Shanghai, Hangzhou, Suzhou, Nanjing, and Wuxi formed a cluster, setting them apart from the rest of the cities. Within the cluster, Shanghai had the least score on cultural amenity, while processing the most urbanized area. On the other hand, Shanghai is closer to the trendline than Suzhou, Nanjing, Hangzhou, and Wuxi. This means if the trendline was used as a standard of reference, Shanghai was at the right place where it should be, relatively speaking. Moreover, all the other top ranking cities were well-positioned with their cultural amenity scores. Zhenjiang, Yangzhou, Shaoxing, and Ningbo were also in the same category of high cultural amenity scores. The R-square values throughout the predicting period, stayed relatively constant, meaning the explanation power of the distribution patterns didn't change very much. This observation was reinforced by the correlation coefficients between the cultural amenity index and the urban growth prediction, as shown in Table 30. There was a gradual increase of the coefficients from 0.2854 in 2011 to 0.2907 in 2030. The matching between the two variables, the cultural amenity and the urban growth prediction, became higher. In scenario 1, the cities with better cultural amenity were actually developed faster than those cities with lower cultural amenity in the Changjiang Delta Region.

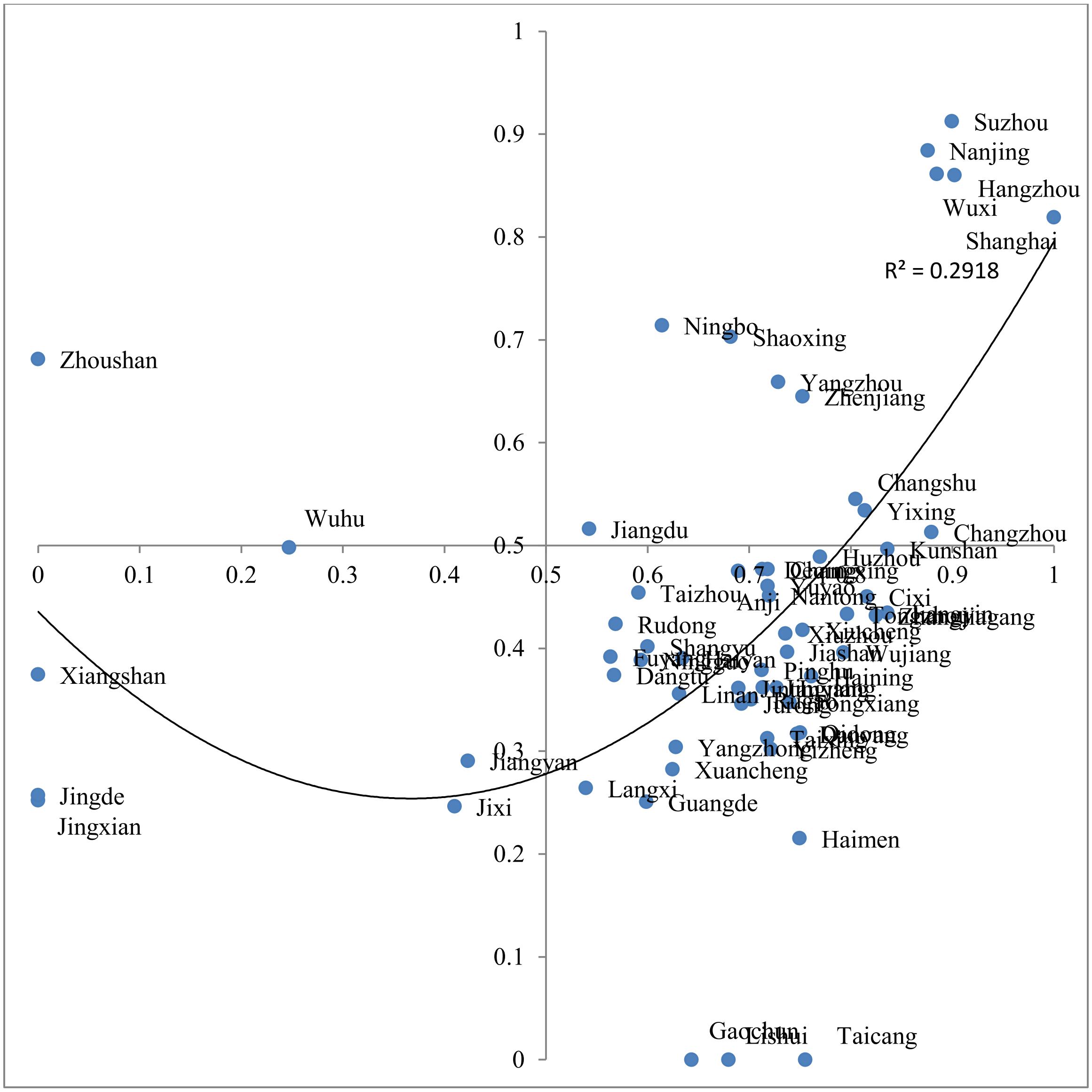


Figure 116. Baseline 3: cultural amenity vs. scenario 1: development corridors, 2011.

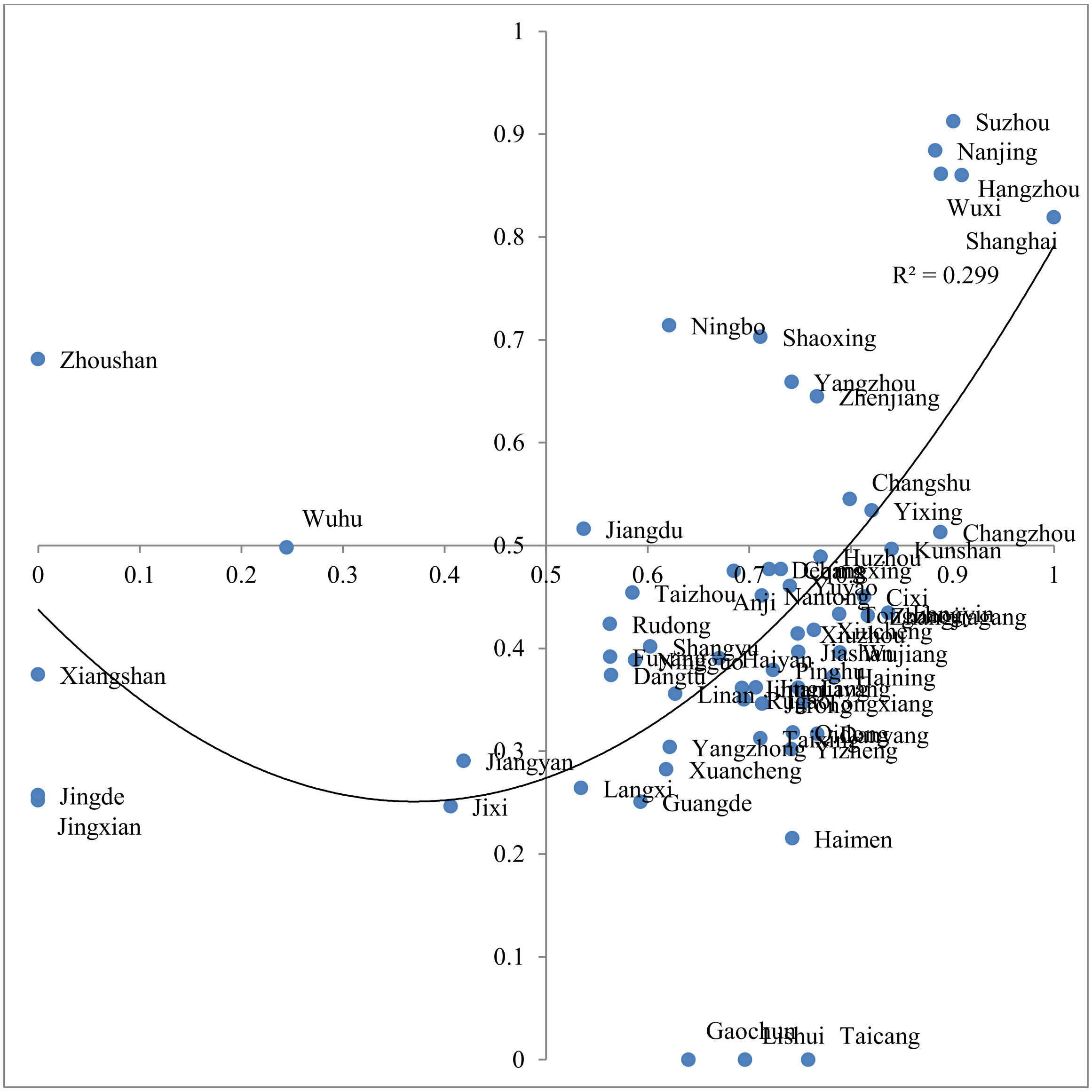


Figure 117. Baseline 3: cultural amenity vs. scenario 1: development corridors, 2020.

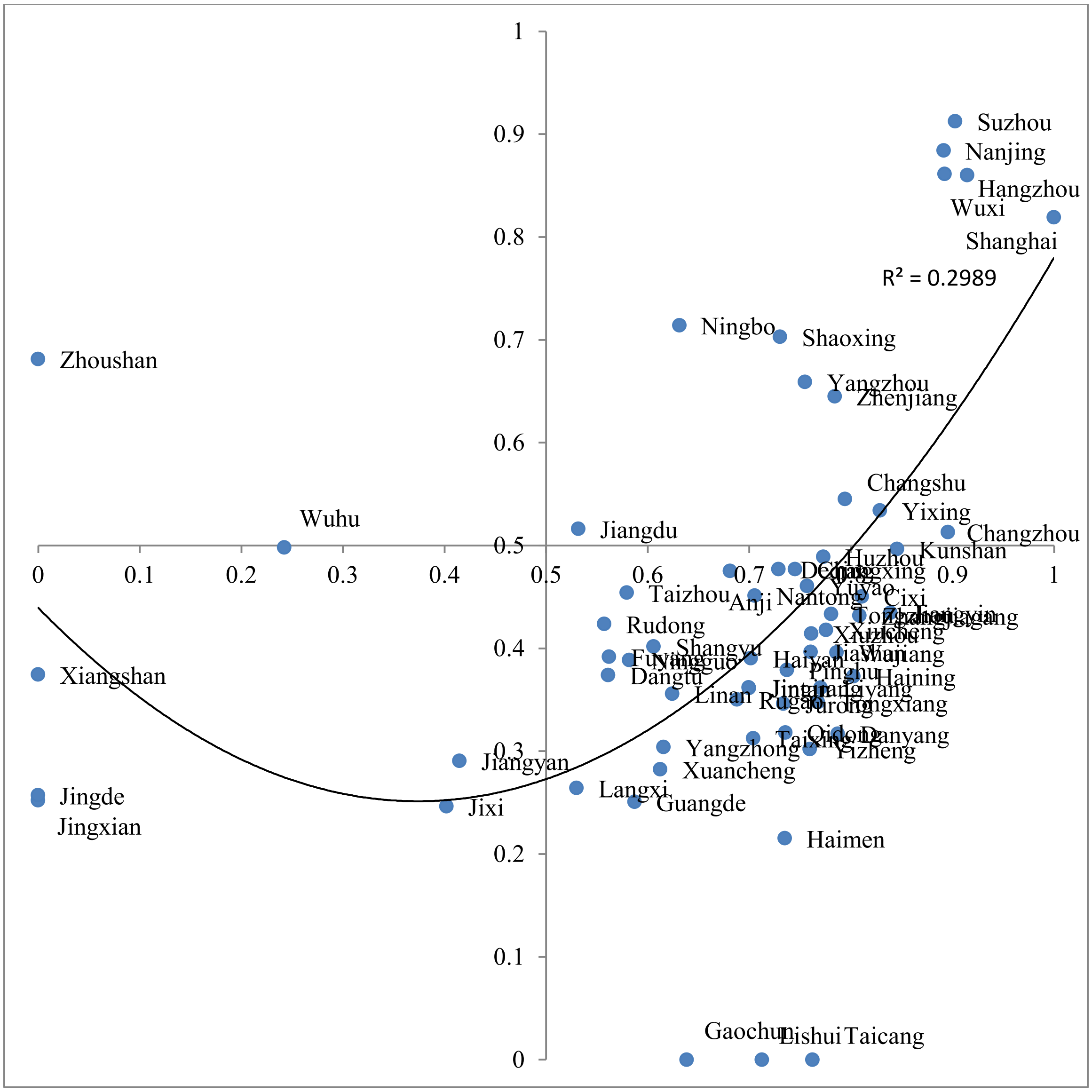


Figure 118. Baseline 3: cultural amenity vs. scenario 1: development corridors, 2030.

Table 30. Correlation coefficient between cultural amenity and urban growth prediction, 2011 to 2030. In the table, var21 is cultural amenity, var1 is 2011, var2 is 2012, and var3 is 2013, and so on. Baseline 3: cultural amenity vs. scenario 1: development corridors.

	var21	*var1*	*var2*	*var3*	*var4*	*var5*	*var6*	*var7*	*var8*	*var9*	*var10*
var21	*1.0000*										
var1	*0.2854*	*1.0000*									
var2	*0.2859*	*1.0000*	*1.0000*								
var3	*0.2862*	*0.9999*	*1.0000*	*1.0000*							
var4	*0.2867*	*0.9999*	*0.9999*	*1.0000*	*1.0000*						
var5	*0.2871*	*0.9998*	*0.9999*	*0.9999*	*1.0000*	*1.0000*					
var6	*0.2875*	*0.9996*	*0.9998*	*0.9999*	*0.9999*	*1.0000*	*1.0000*				
var7	*0.2879*	*0.9995*	*0.9996*	*0.9998*	*0.9999*	*0.9999*	*1.0000*	*1.0000*			
var8	*0.2883*	*0.9993*	*0.9995*	*0.9996*	*0.9998*	*0.9999*	*0.9999*	*1.0000*	*1.0000*		
var9	*0.2886*	*0.9991*	*0.9993*	*0.9995*	*0.9997*	*0.9998*	*0.9999*	*0.9999*	*1.0000*	*1.0000*	
var10	*0.2889*	*0.9989*	*0.9991*	*0.9993*	*0.9995*	*0.9997*	*0.9998*	*0.9999*	*0.9999*	*1.0000*	*1.0000*

	var21	*var11*	*var12*	*var13*	*var14*	*var15*	*var16*	*var17*	*var18*	*var19*	*var20*
var21	*1.0000*										
var11	*0.2892*	*1.0000*									
var12	*0.2895*	*1.0000*	*1.0000*								
var13	*0.2897*	*1.0000*	*1.0000*	*1.0000*							
var14	*0.2899*	*0.9999*	*1.0000*	*1.0000*	*1.0000*						
var15	*0.2901*	*0.9998*	*0.9999*	*1.0000*	*1.0000*	*1.0000*					
var16	*0.2902*	*0.9997*	*0.9998*	*0.9999*	*1.0000*	*1.0000*	*1.0000*				
var17	*0.2903*	*0.9996*	*0.9998*	*0.9998*	*0.9999*	*1.0000*	*1.0000*	*1.0000*			
var18	*0.2905*	*0.9995*	*0.9997*	*0.9998*	*0.9999*	*0.9999*	*1.0000*	*1.0000*	*1.0000*		
var19	*0.2906*	*0.9994*	*0.9995*	*0.9997*	*0.9998*	*0.9999*	*0.9999*	*1.0000*	*1.0000*	*1.0000*	
var20	*0.2907*	*0.9992*	*0.9994*	*0.9996*	*0.9997*	*0.9998*	*0.9999*	*0.9999*	*1.0000*	*1.0000*	*1.0000*

The correlation coefficients were projected to a line table, as shown in Figure 119, with a very high R-square and an ascending value. The high value explained the consistent linear trend of coefficient's movement, and ascending value further supported the tendency of better matching between cultural amenity and urban growth prediction.

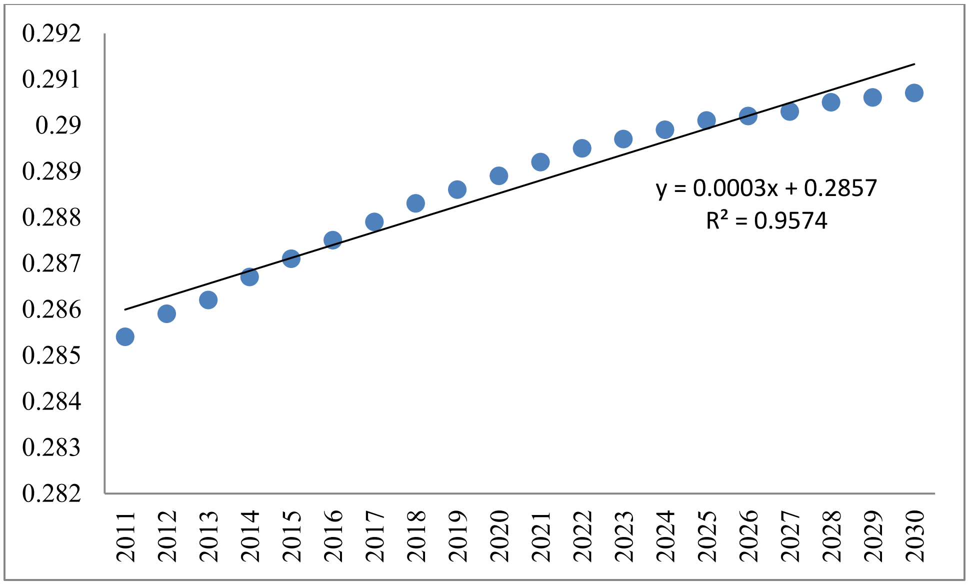


Figure 119. Correlation coefficients projected by years, 2011-2030, baseline 3: cultural amenity vs. scenario 1: development corridors.

ii. Baseline 3: cultural amenities vs. scenario 2: development corridors, plus big city growth.

Results from three selected years were shown for baseline 3: cultural amenities versus scenario 2: development corridors, plus big city growth. Figures 120, 121, and 122 revealed that Shanghai possessed relatively appropriate amount of cultural amenity according to its land urbanization and urban growth prediction and Suzhou, Nanjing, Hangzhou, and Wuxi were well-positioned in terms of the cultural amenity index. One noticeable fact for this scenario was the logarithmic shape of the trend line. In Table 31, the correlation coefficient between cultural amenity and urban growth prediction started with 0.2861, peaked in 2023 with 0.2927 and then gradually dropping to 0.2924 in 2030. It means that after 2023, the cities with high scored cultural amenity were not urbanized as fast as before 2023. While this observation could serve as a precautious warning, however, the cultural amenity index itself might change as the urbanization form of the Changjiang Delta Region evolves.

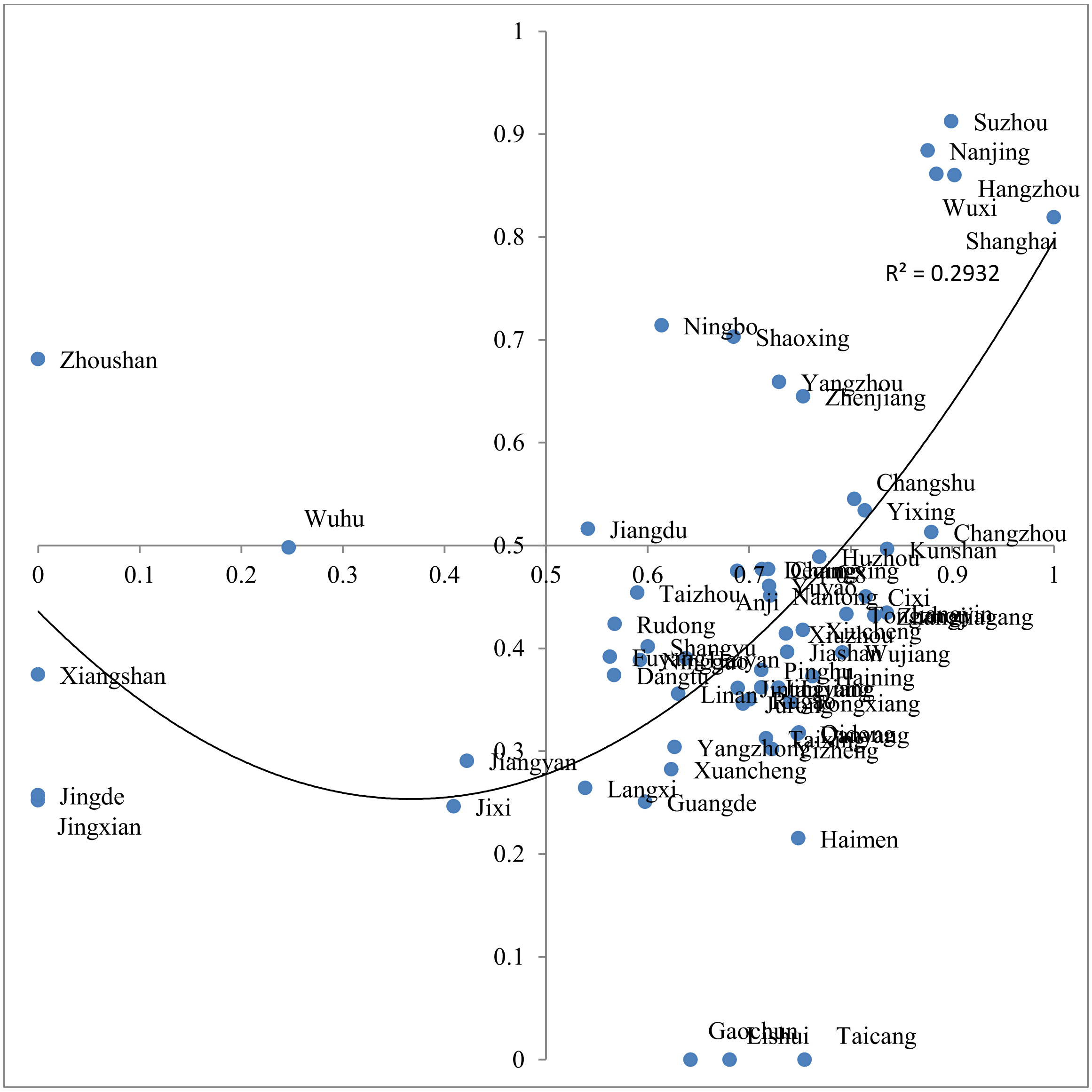


Figure 120. Baseline 3: cultural amenity vs. scenario 2: development corridors, plus big cities growth, 2011.

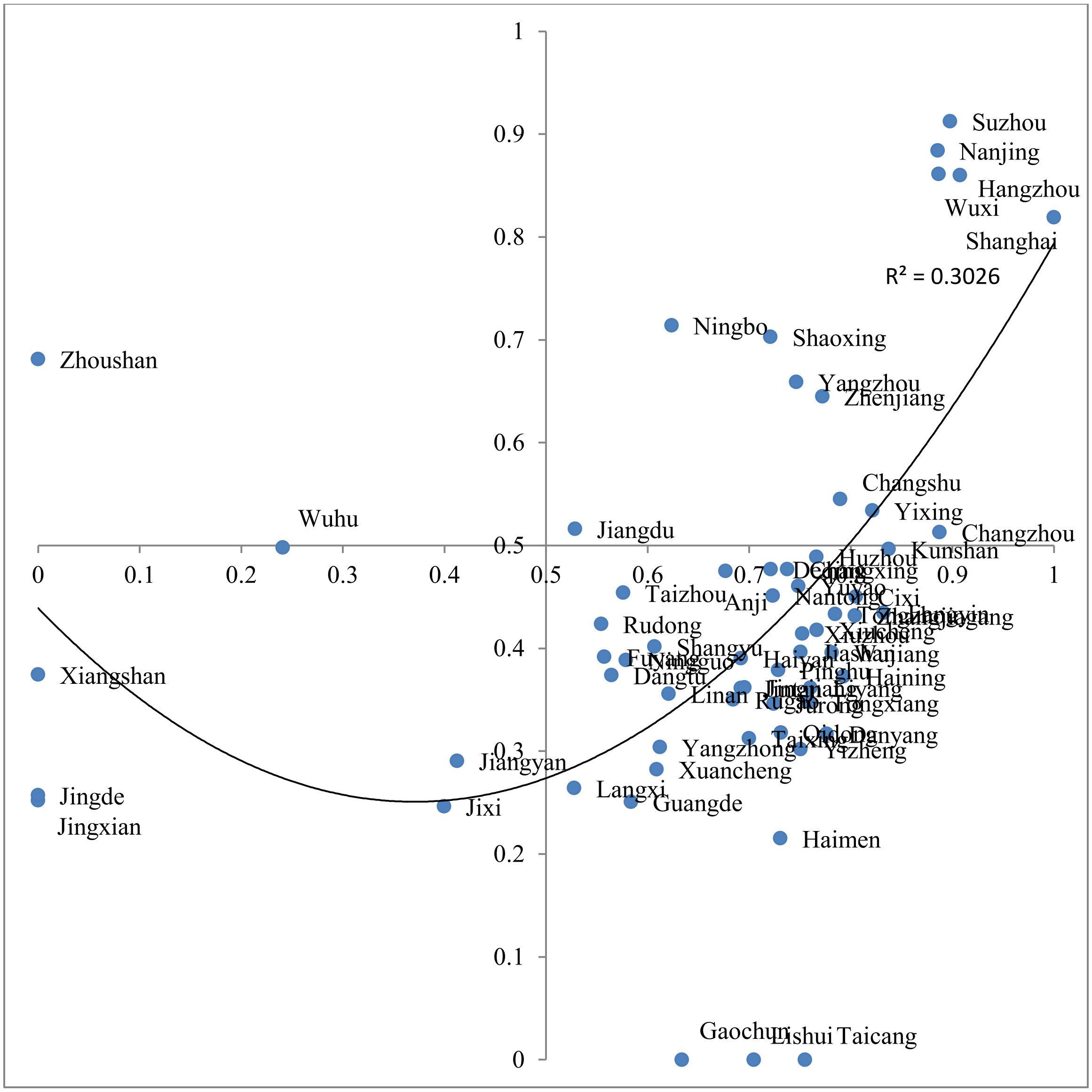


Figure 121. Baseline 3: cultural amenity vs. scenario 2: development corridors, plus big cities growth, 2020.

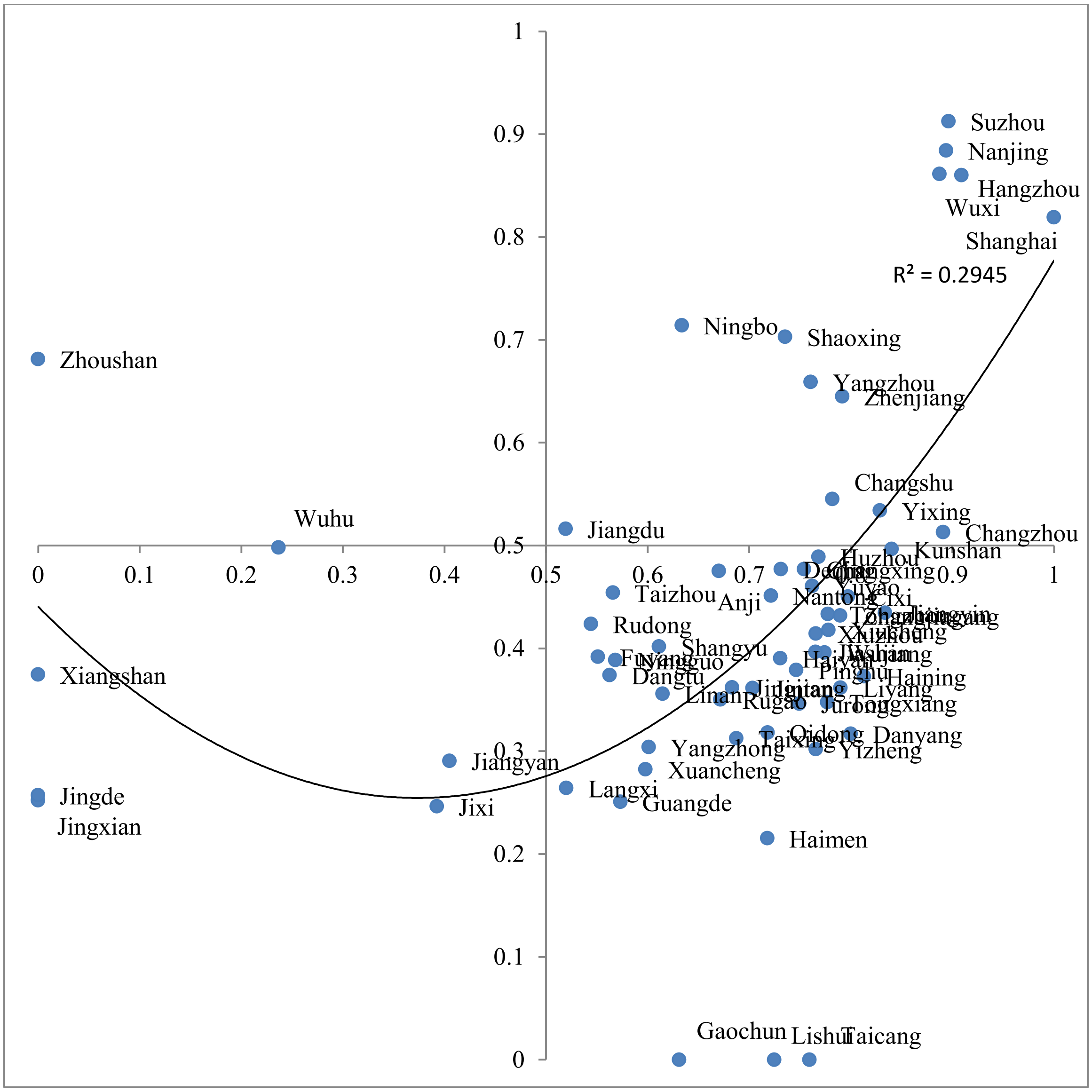


Figure 122. Baseline 3: cultural amenity vs. scenario 2: development corridors, plus big cities growth, 2030.

Table 31. Correlation coefficient between cultural amenity and urban growth prediction from 2011 to 2030. In the table, var21 is cultural amenity, var1 is 2011, var2 is 2012, and var3 is 2013, and so on. Baseline 3: cultural amenity vs. scenario 2: development corridors, plus big cities growth.

	var21	*var1*	*var2*	*var3*	*var4*	*var5*	*var6*	*var7*	*var8*	*var9*	*var10*
var21	*1.0000*										
var1	*0.2861*	*1.0000*									
var2	*0.2871*	*1.0000*	*1.0000*								
var3	*0.2880*	*0.9998*	*1.0000*	*1.0000*							
var4	*0.2888*	*0.9996*	*0.9998*	*1.0000*	*1.0000*						
var5	*0.2896*	*0.9993*	*0.9996*	*0.9998*	*1.0000*	*1.0000*					
var6	*0.2902*	*0.9989*	*0.9993*	*0.9996*	*0.9998*	*1.0000*	*1.0000*				
var7	*0.2909*	*0.9985*	*0.9990*	*0.9994*	*0.9997*	*0.9999*	*1.0000*	*1.0000*			
var8	*0.2913*	*0.9981*	*0.9987*	*0.9991*	*0.9995*	*0.9997*	*0.9999*	*1.0000*	*1.0000*		
var9	*0.2917*	*0.9976*	*0.9983*	*0.9988*	*0.9992*	*0.9995*	*0.9997*	*0.9999*	*1.0000*	*1.0000*	
var10	*0.2921*	*0.9972*	*0.9978*	*0.9984*	*0.9989*	*0.9993*	*0.9996*	*0.9998*	*0.9999*	*1.0000*	*1.0000*

	var21	*var11*	*var12*	*var13*	*var14*	*var15*	*var16*	*var17*	*var18*	*var19*	*var20*
var21	*1.0000*										
var11	*0.2924*	*1.0000*									
var12	*0.2926*	*1.0000*	*1.0000*								
var13	*0.2927*	*0.9999*	*1.0000*	*1.0000*							
var14	*0.2927*	*0.9998*	*0.9999*	*1.0000*	*1.0000*						
var15	*0.2927*	*0.9997*	*0.9998*	*0.9999*	*1.0000*	*1.0000*					
var16	*0.2927*	*0.9996*	*0.9997*	*0.9999*	*0.9999*	*1.0000*	*1.0000*				
var17	*0.2927*	*0.9994*	*0.9996*	*0.9998*	*0.9999*	*0.9999*	*1.0000*	*1.0000*			
var18	*0.2927*	*0.9992*	*0.9995*	*0.9996*	*0.9998*	*0.9999*	*0.9999*	*1.0000*	*1.0000*		
var19	*0.2925*	*0.9990*	*0.9993*	*0.9995*	*0.9997*	*0.9998*	*0.9999*	*1.0000*	*1.0000*	*1.0000*	
var20	*0.2924*	*0.9988*	*0.9991*	*0.9993*	*0.9995*	*0.9997*	*0.9998*	*0.9999*	*1.0000*	*1.0000*	*1.0000*

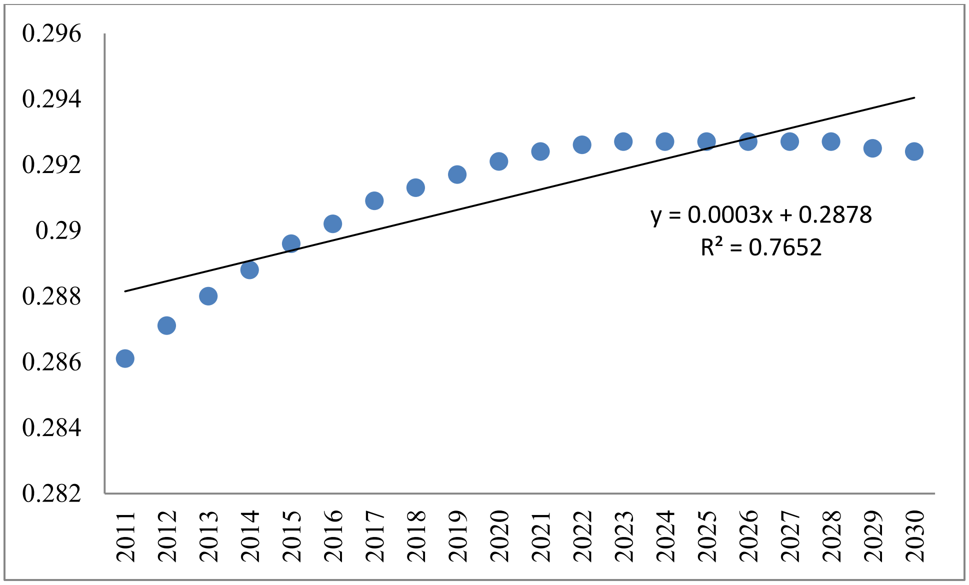


Figure 123. Correlation coefficients projected by years, 2011-2030, baseline 3: cultural amenity vs. scenario 2: development corridors, plus big cities growth.

Baseline 3: cultural amenities vs. scenario 3: ecological system concerns (i.e. forest protection), plus development corridors.

Results from three selected years were shown for baseline 3: cultural amenities versus scenario 3: ecological system concerns (forest protection), plus development corridors. This scenario resembles scenario 1: development corridors, with moderately higher R-square numbers. The explanation and implication of the results are also similar to scenario 1.

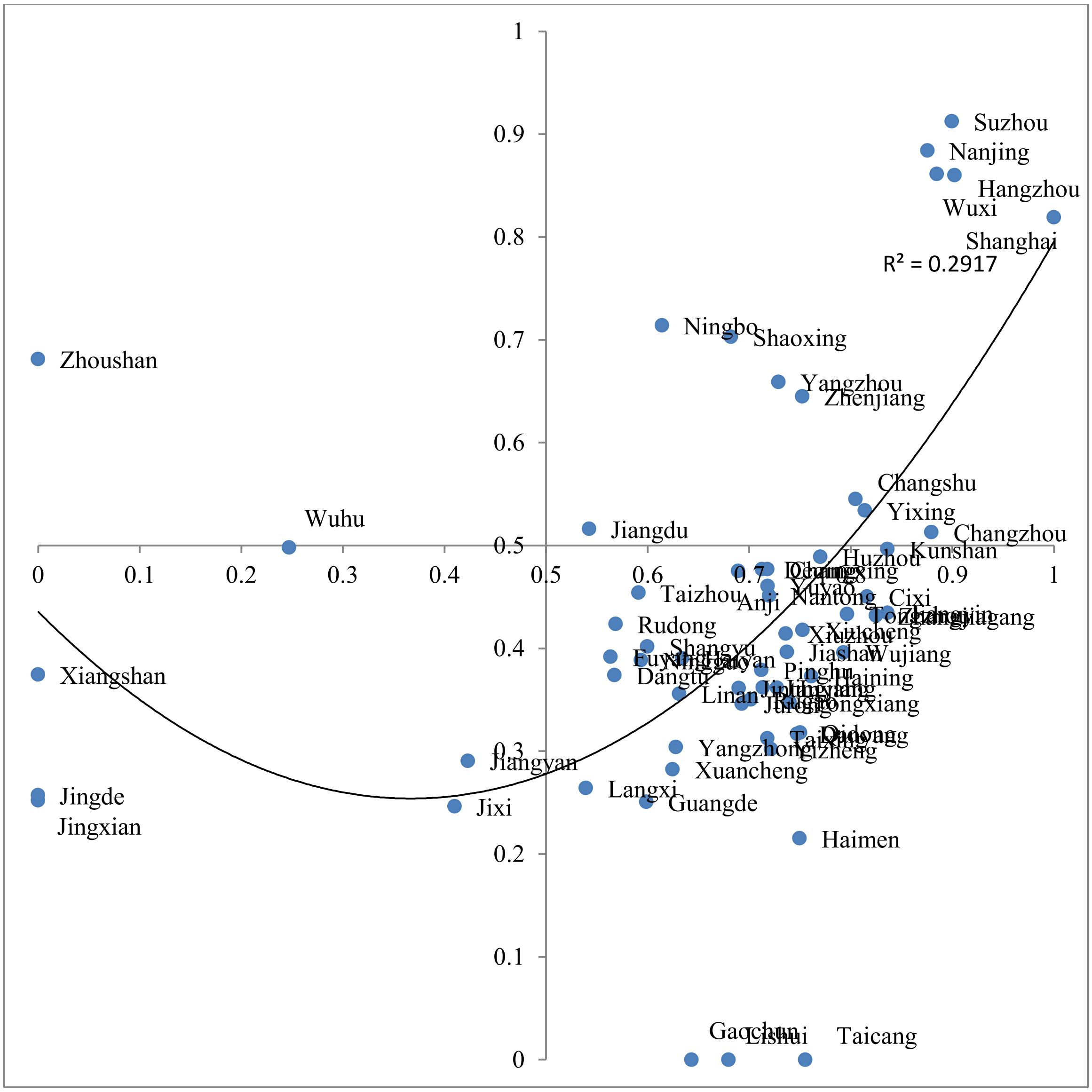


Figure 124. Baseline 3: cultural amenities vs. scenario 3: ecological system concerns (forest protection), plus development corridors, 2011.

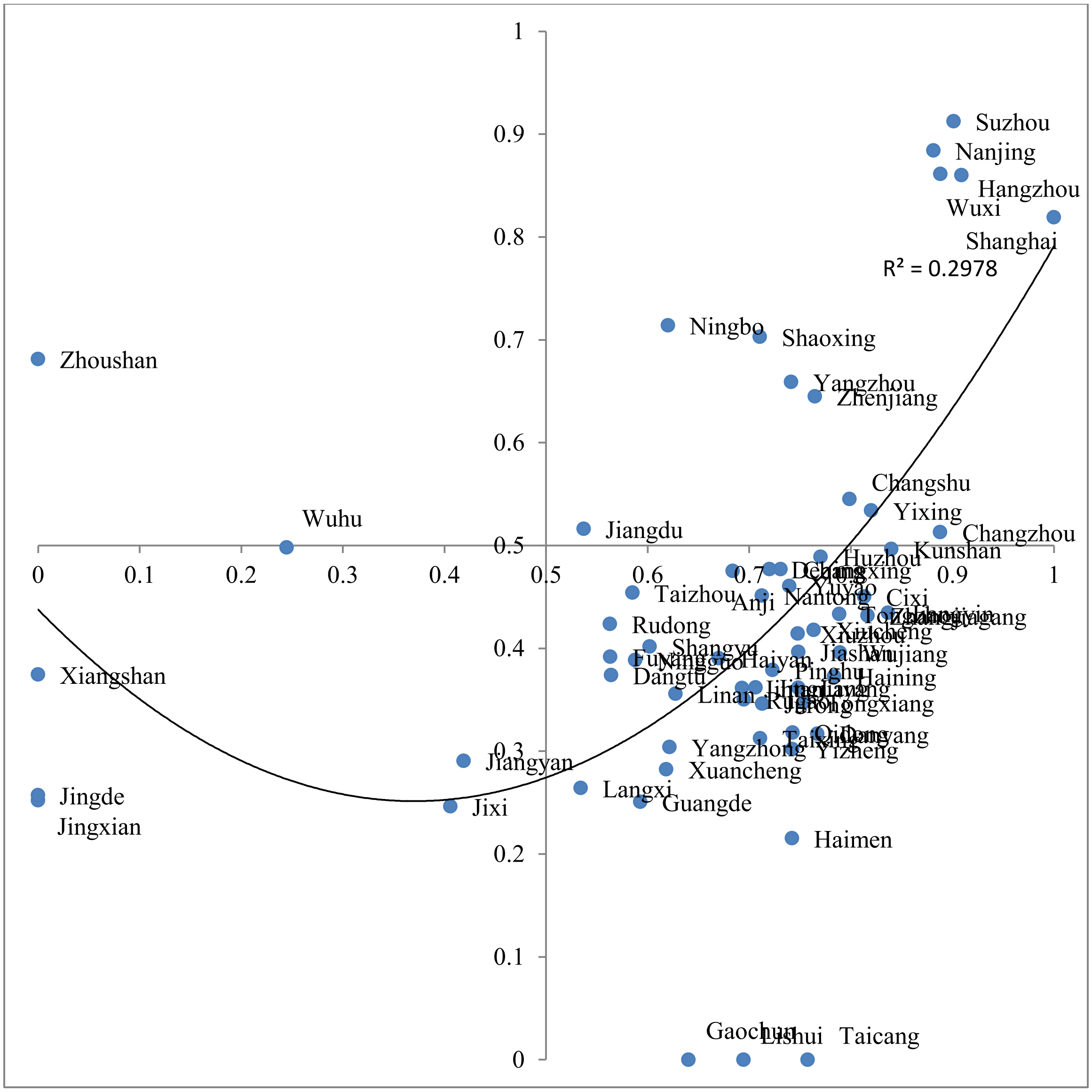


Figure 125. Baseline 3: cultural amenities vs. scenario 3: ecological system concerns (forest protection), plus development corridors, 2020.

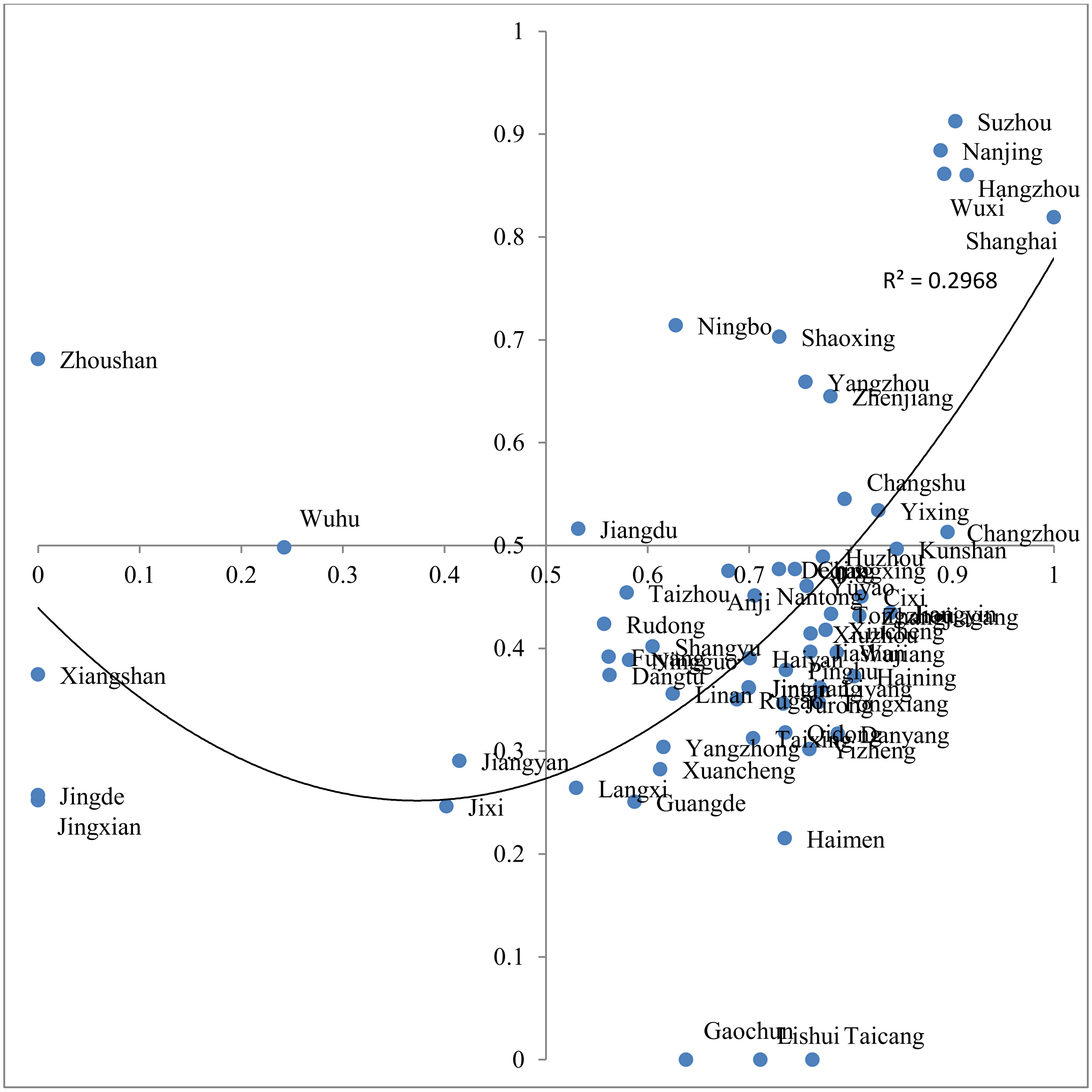


Figure 126. Baseline 3: cultural amenities vs. scenario 3: ecological system concerns (forest protection), plus development corridors, 2030.

The cultural amenities and the urban growth data of scenario 3: ecological system concern, plus development corridors were put in to Stata to calculate correlation coefficient. The results are reproduced in Table 32.

Table 32. Correlation coefficient between cultural amenity and urban growth prediction from 2011 to 2030. In the table, var21 is cultural amenity, var1 is 2011, var2 is 2012, and var3 is 2013, and so on. Baseline 3: cultural amenities versus scenario 3: ecological system concerns (forest protection), plus development corridors.

	var21	*var1*	*var2*	*var3*	*var4*	*var5*	*var6*	*var7*	*var8*	*var9*	*var10*
var21	*1.0000*										
var1	*0.2854*	*1.0000*									
var2	*0.2858*	*1.0000*	*1.0000*								
var3	*0.2863*	*0.9999*	*1.0000*	*1.0000*							
var4	*0.2866*	*0.9999*	*0.9999*	*1.0000*	*1.0000*						
var5	*0.2870*	*0.9998*	*0.9999*	*0.9999*	*1.0000*	*1.0000*					
var6	*0.2873*	*0.9996*	*0.9998*	*0.9999*	*0.9999*	*1.0000*	*1.0000*				
var7	*0.2876*	*0.9995*	*0.9996*	*0.9998*	*0.9999*	*0.9999*	*1.0000*	*1.0000*			
var8	*0.2879*	*0.9993*	*0.9995*	*0.9997*	*0.9998*	*0.9999*	*0.9999*	*1.0000*	*1.0000*		
var9	*0.2882*	*0.9991*	*0.9993*	*0.9995*	*0.9997*	*0.9998*	*0.9999*	*0.9999*	*1.0000*	*1.0000*	
var10	*0.2885*	*0.9989*	*0.9991*	*0.9993*	*0.9995*	*0.9997*	*0.9998*	*0.9999*	*1.0000*	*1.0000*	*1.0000*

	var21	*var11*	*var12*	*var13*	*var14*	*var15*	*var16*	*var17*	*var18*	*var19*	*var20*
var21	*1.0000*										
var11	*0.2887*	*1.0000*									
var12	*0.2889*	*1.0000*	*1.0000*								
var13	*0.2891*	*1.0000*	*1.0000*	*1.0000*							
var14	*0.2893*	*0.9999*	*1.0000*	*1.0000*	*1.0000*						
var15	*0.2894*	*0.9998*	*0.9999*	*1.0000*	*1.0000*	*1.0000*					
var16	*0.2895*	*0.9998*	*0.9998*	*0.9999*	*1.0000*	*1.0000*	*1.0000*				
var17	*0.2897*	*0.9997*	*0.9998*	*0.9999*	*0.9999*	*1.0000*	*1.0000*	*1.0000*			
var18	*0.2897*	*0.9995*	*0.9997*	*0.9998*	*0.9999*	*0.9999*	*1.0000*	*1.0000*	*1.0000*		
var19	*0.2897*	*0.9994*	*0.9996*	*0.9997*	*0.9998*	*0.9999*	*0.9999*	*1.0000*	*1.0000*	*1.0000*	
var20	*0.2898*	*0.9993*	*0.9994*	*0.9996*	*0.9997*	*0.9998*	*0.9999*	*0.9999*	*1.0000*	*1.0000*	*1.0000*

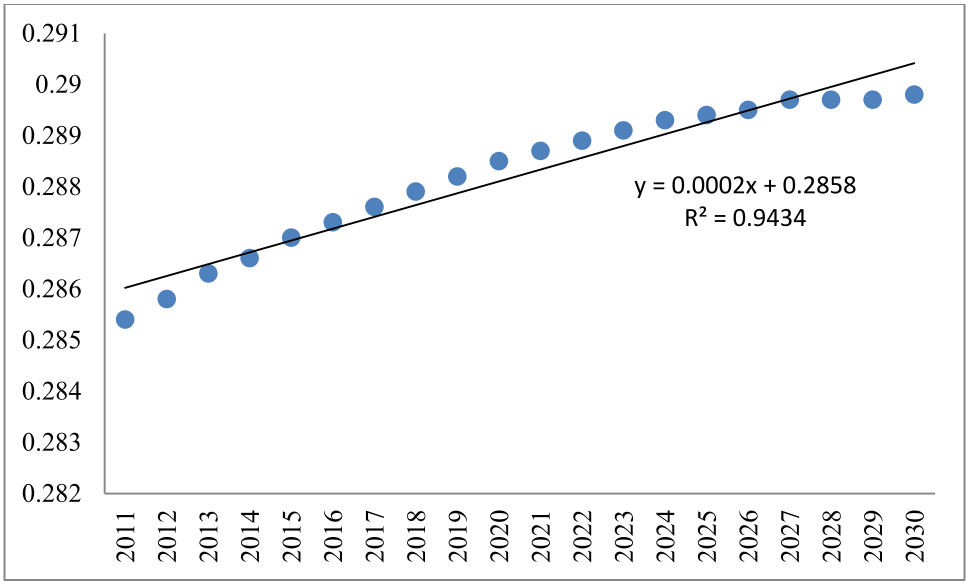


Figure 127. Correlation coefficients projected by years, 2011-2030, Baseline 3: cultural amenities versus scenario 3: ecological system concerns (forest protection), plus development corridors.

Baseline 3: cultural amenities vs. scenario 4: disaster prevention, plus development corridors.

Results from three selected years were shown for baseline 3: cultural amenities versus scenario 4: disaster prevention, plus development corridors. The difference for this scenario, comparing with the previous three, is the descending values of correlation coefficients. It means that the cities with higher cultural amenity index scores didn't urbanize as fast as the cities with lower scores. The solutions can be either increasing the cultural amenity facilities for the low scored cities or provide pro-growth policy for those with high scores.

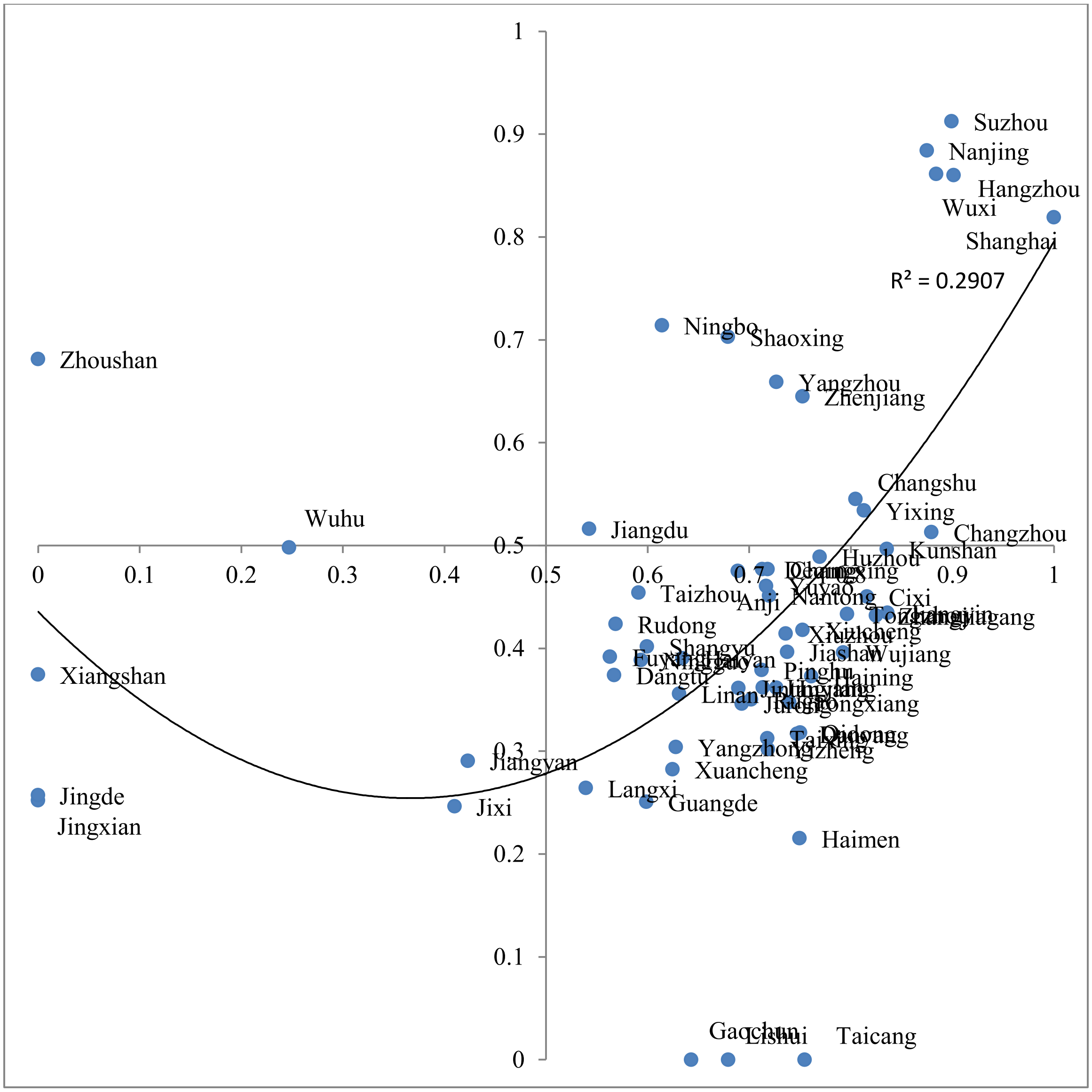


Figure 128. Baseline 3: cultural amenities versus scenario 4: disaster prevention, plus development corridors, 2011.

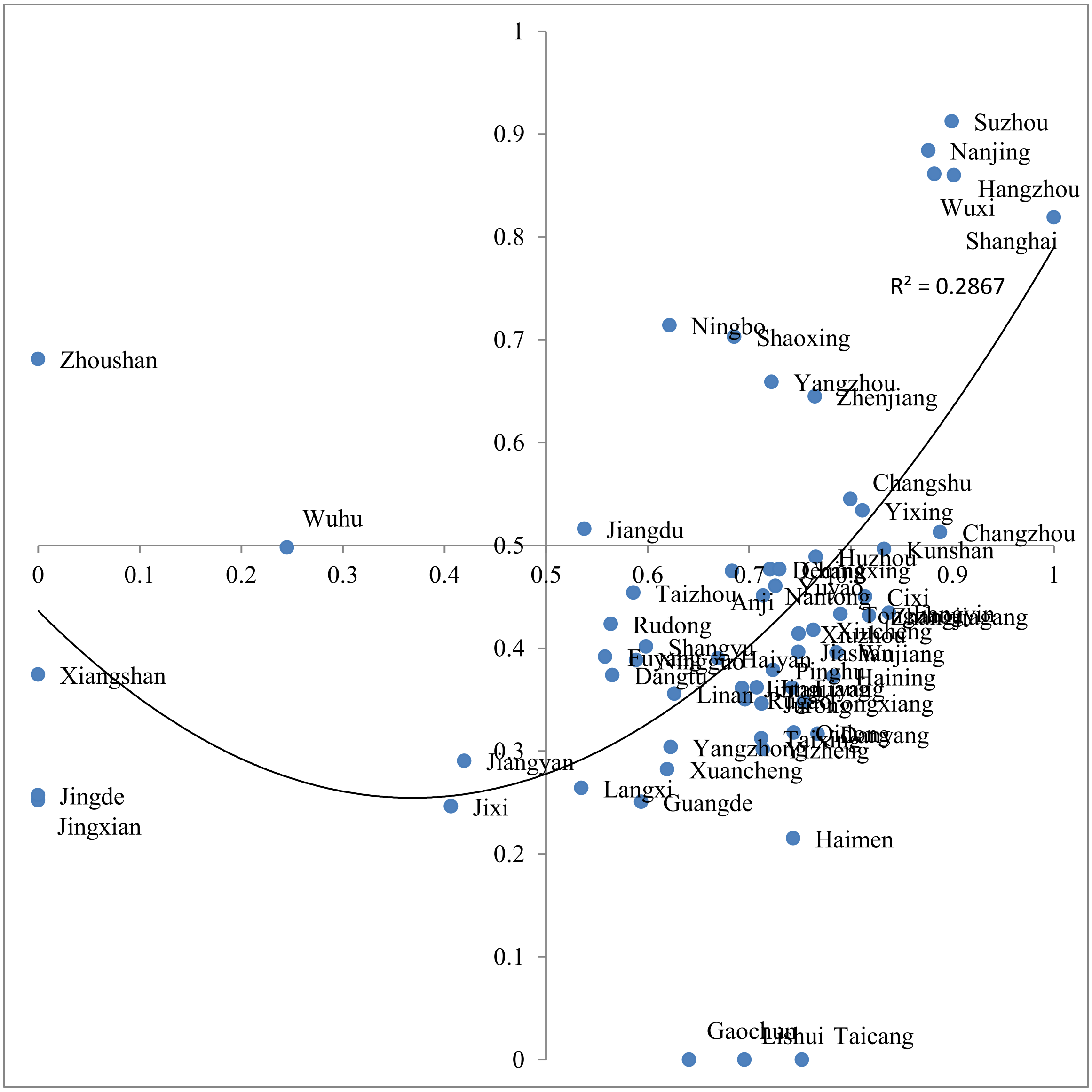


Figure 129. Baseline 3: cultural amenities vs. scenario 4: disaster prevention, plus development corridors, 2020.

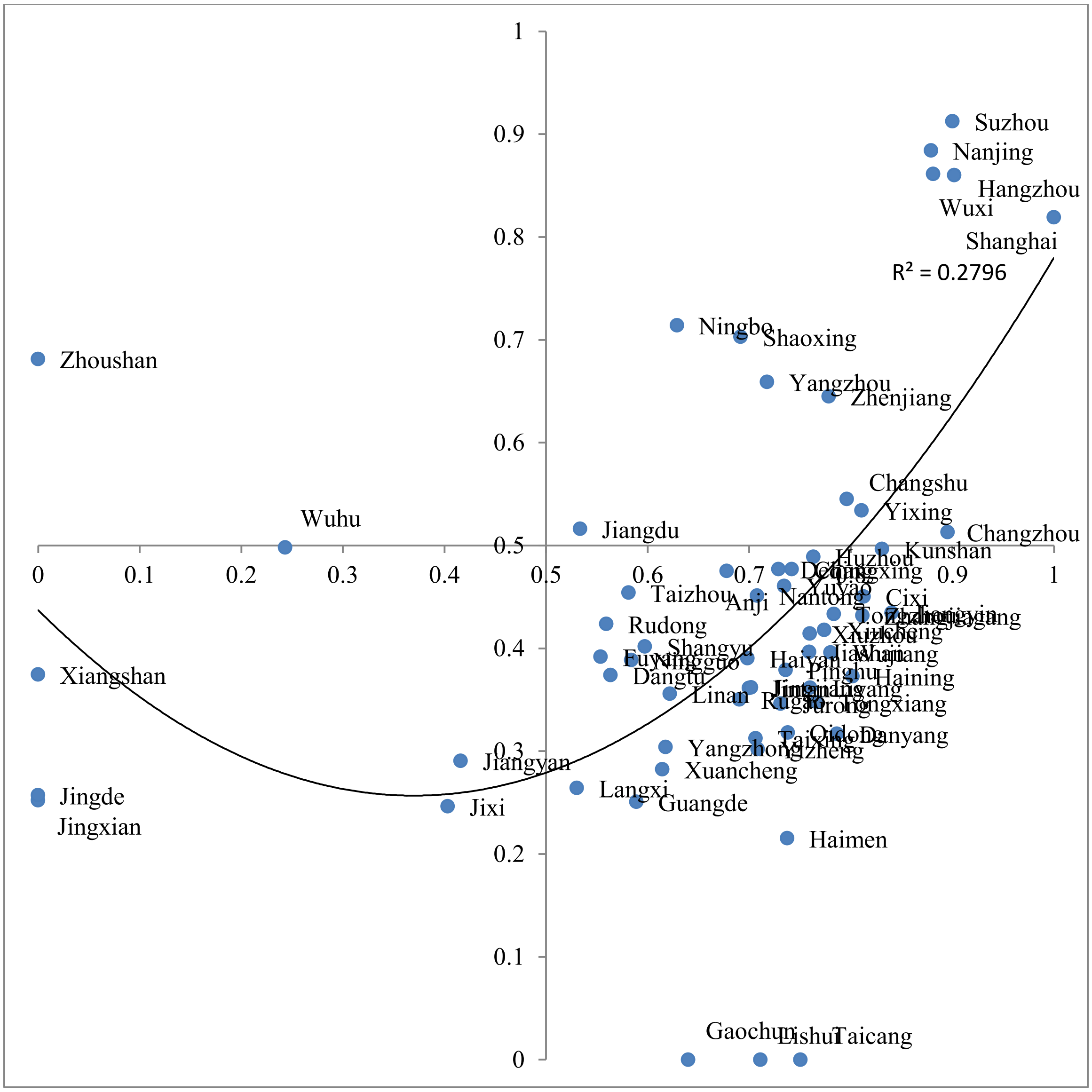


Figure 130. Baseline 3: cultural amenities vs. scenario 4: disaster prevention, plus development corridors, 2030.

The economic performance and the urban growth data of scenario 4 were put in to Stata to calculate correlation coefficient. The results are reproduced here:

Table 33. Correlation coefficient between cultural amenity and urban growth prediction from 2011 to 2030. In the table, var21 is cultural amenity, var1 is 2011, var2 is 2012, and var3 is 2013, and so on. Baseline 3: cultural amenities versus scenario 4: disaster prevention, plus development corridors 4.

	var21	*var1*	*var2*	*var3*	*var4*	*var5*	*var6*	*var7*	*var8*	*var9*	*var10*
var21	*1.0000*										
var1	*0.2850*	*1.0000*									
var2	*0.2847*	*1.0000*	*1.0000*								
var3	*0.2846*	*1.0000*	*1.0000*	*1.0000*							
var4	*0.2843*	*0.9999*	*1.0000*	*1.0000*	*1.0000*						
var5	*0.2841*	*0.9998*	*0.9999*	*1.0000*	*1.0000*	*1.0000*					
var6	*0.2840*	*0.9997*	*0.9998*	*0.9999*	*1.0000*	*1.0000*	*1.0000*				
var7	*0.2838*	*0.9996*	*0.9997*	*0.9998*	*0.9999*	*1.0000*	*1.0000*	*1.0000*			
var8	*0.2837*	*0.9995*	*0.9996*	*0.9997*	*0.9998*	*0.9999*	*1.0000*	*1.0000*	*1.0000*		
var9	*0.2836*	*0.9993*	*0.9995*	*0.9996*	*0.9997*	*0.9998*	*0.9999*	*1.0000*	*1.0000*	*1.0000*	
var10	*0.2833*	*0.9991*	*0.9993*	*0.9995*	*0.9996*	*0.9997*	*0.9998*	*0.9999*	*1.0000*	*1.0000*	*1.0000*

	var21	*var11*	*var12*	*var13*	*var14*	*var15*	*var16*	*var17*	*var18*	*var19*	*var20*
var21	*1.0000*										
var11	*0.2831*	*1.0000*									
var12	*0.2830*	*1.0000*	*1.0000*								
var13	*0.2829*	*1.0000*	*1.0000*	*1.0000*							
var14	*0.2826*	*0.9999*	*1.0000*	*1.0000*	*1.0000*						
var15	*0.2824*	*0.9999*	*0.9999*	*1.0000*	*1.0000*	*1.0000*					
var16	*0.2823*	*0.9998*	*0.9999*	*0.9999*	*1.0000*	*1.0000*	*1.0000*				
var17	*0.2820*	*0.9997*	*0.9998*	*0.9999*	*0.9999*	*1.0000*	*1.0000*	*1.0000*			
var18	*0.2819*	*0.9996*	*0.9997*	*0.9998*	*0.9999*	*0.9999*	*1.0000*	*1.0000*	*1.0000*		
var19	*0.2817*	*0.9995*	*0.9996*	*0.9997*	*0.9998*	*0.9999*	*0.9999*	*1.0000*	*1.0000*	*1.0000*	
var20	*0.2815*	*0.9994*	*0.9996*	*0.9997*	*0.9998*	*0.9998*	*0.9999*	*0.9999*	*1.0000*	*1.0000*	*1.0000*

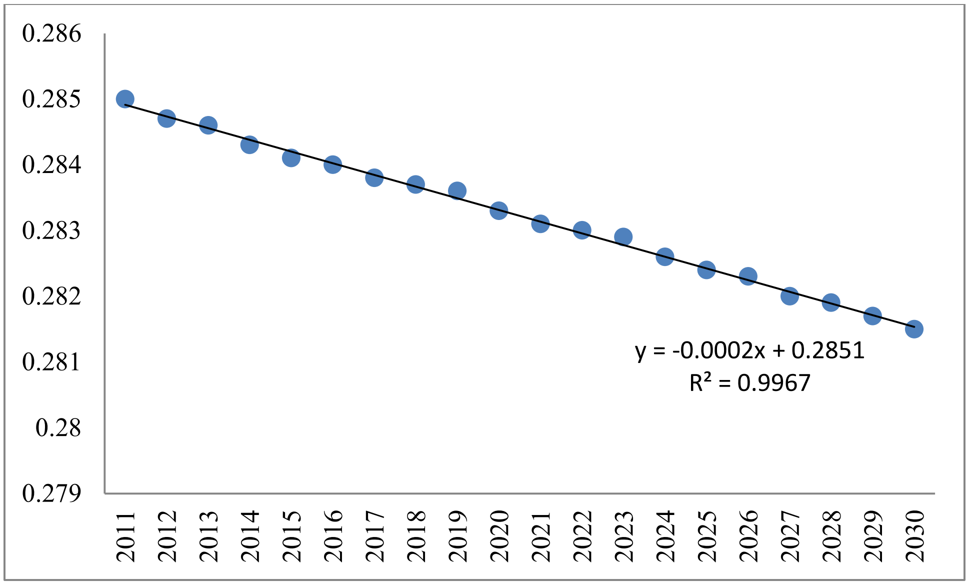


Figure 131. Correlation coefficients projected by years, 2011-2030, baseline 3: cultural amenity versus scenario 4: disaster prevention, plus development corridors 4.

In summary, the correlation coefficients between baseline 3: cultural amenity and scenario 1, 2, and 3 all exhibited ascending values, however, for scenario 4, the coefficients exhibited descending values. If the regional urban growth strategy takes disaster prevention into account, it should also reflect polices that consider resource allocation for cultural amenity.

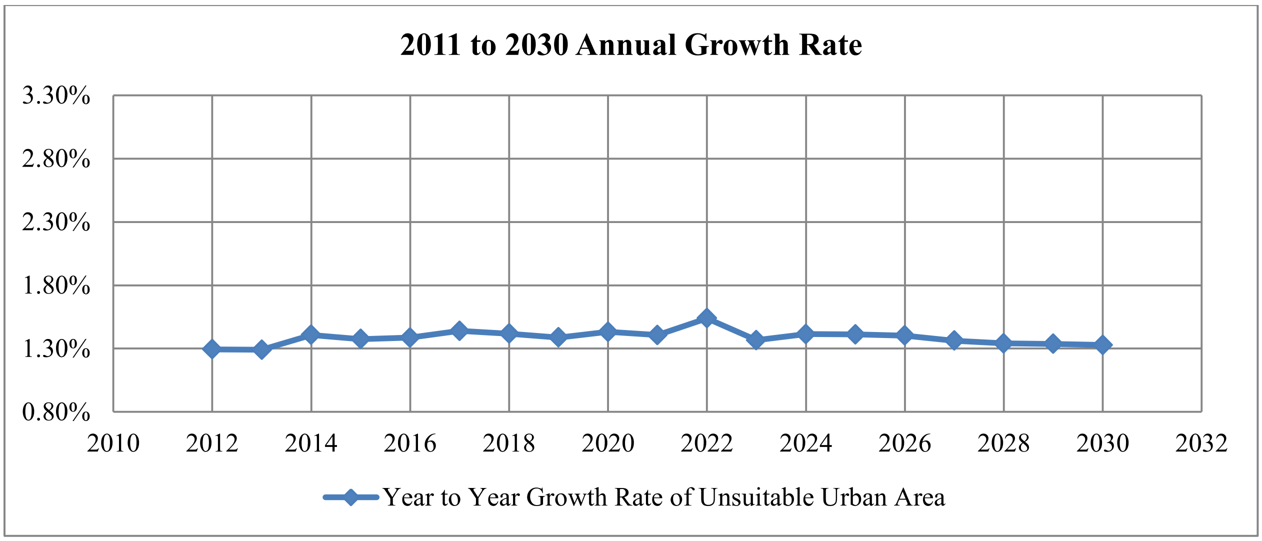
Chapter 5. Discussions and conclusions

In order to achieve an enhanced spatial distribution for a regional urban network, a few questions are critical for decision making regarding future development. They are: should big cities grow bigger? What's the merit of disaster prevention? Does 'good' urban development policy induce good urban form? How to interpret rank order and improve regional urban network efficiency? Each of these questions is now discussed within the urban growth case study of the Changjiang Delta Region.

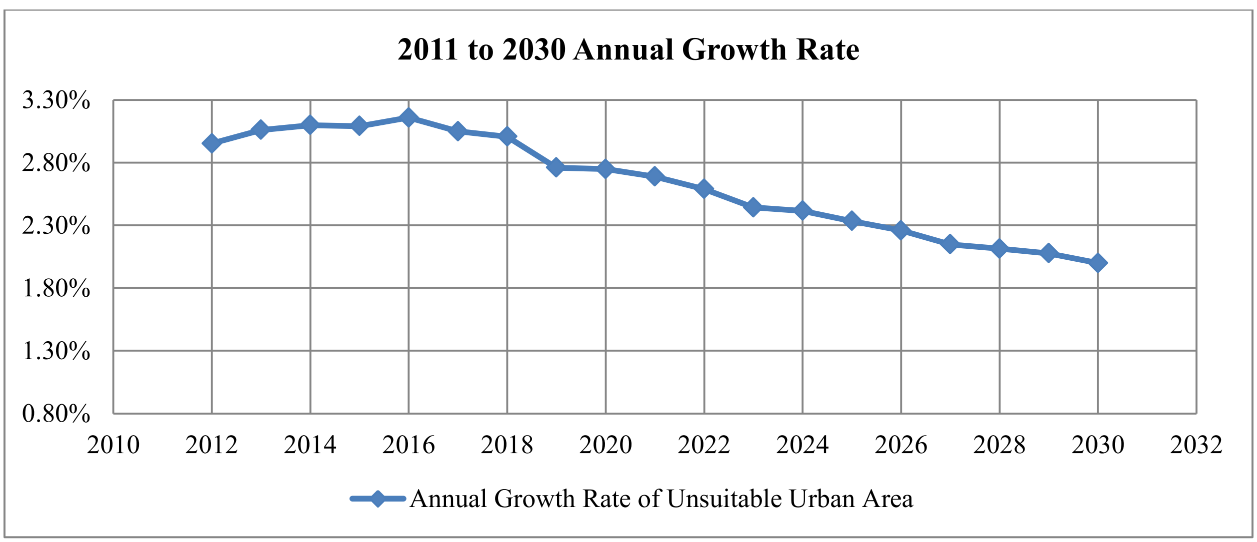
1. Should big cities grow bigger?

It is important to interpret each individual scenario by comparing them together. The annual growth rate figures are reproduced here for all four scenarios. Notice that the y axis of each figure is now set to the same numbers with a minimum of 0.8% and a maximum of 3.3%. In Figure 1 baseline 1: environmental suitability vs. scenario 1: development corridors, the peak in 2022 disappeared and the graph exhibited a relatively smooth tendency throughout the study years until 2030. The bumps in baseline 1: environmental suitability vs. scenario 3: ecological system concerns, plus development corridors and baseline 1: environmental suitability vs. scenario 4: disaster prevention, plus development corridors were also alleviated to a degree that no significant cycles of ups and downs existed. It's worth mentioning that in baseline 1: environmental suitability vs. scenario 2: development corridors, plus big city growth, the high rate of annual growth rate of urbanization in unsuitable urban areas became more evident compared with the other three scenarios. From the starting year of 2012 on 2011, the growth rate was always the highest among the four scenarios. Even though the declining trend after 2016, the lowest number of 2030 on 2029 is still larger than any other years of all other scenarios.

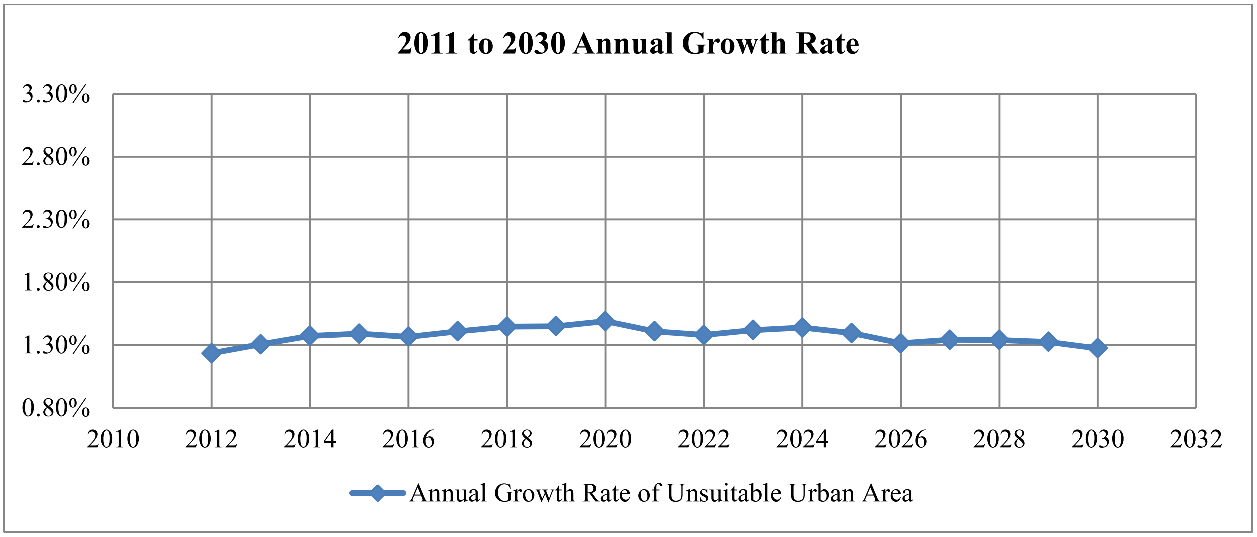
Based on the above analysis, a conclusion can be made: Further growth of big cities in the Changjiang Delta Region is not an environmentally responsive policy. Even though big cities have done a great job in terms of environmental resource consumption per capita so far, further expansion could bring more harmful consequences than before. It reinforced the results and



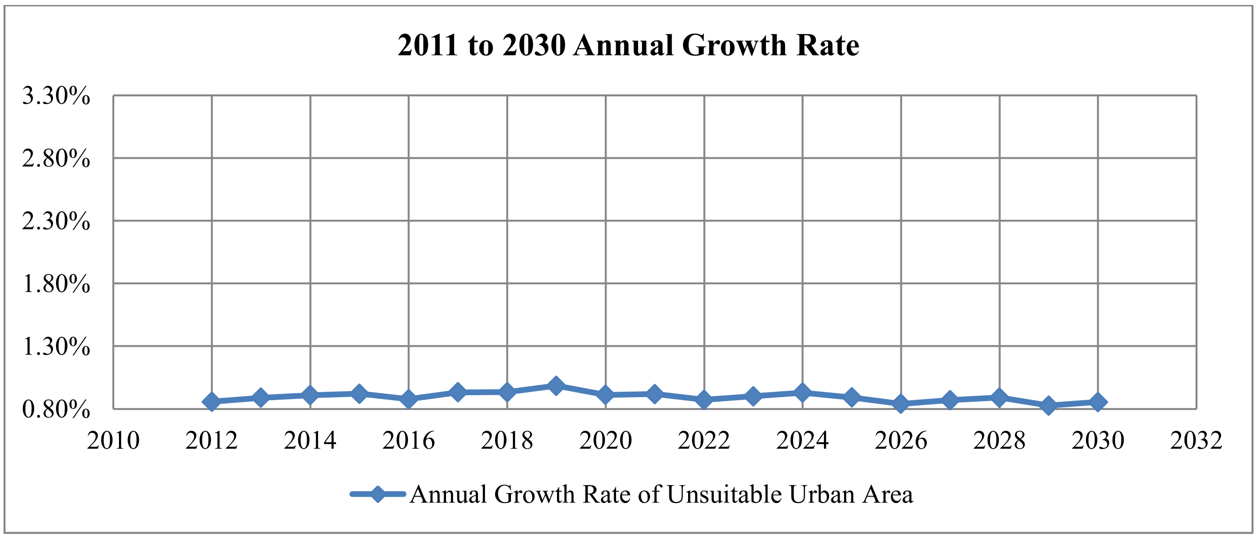
Baseline 1: environmental suitability vs. scenario 1: development corridors.



Baseline 1: environmental suitability vs. scenario 2: development corridors, plus big city growth.



Baseline 1: environmental suitability vs. scenario 3: ecological system concerns, plus development corridors.



Baseline 1: environmental suitability vs. scenario 4: disaster prevention, plus development corridors

Figure 1. Annual growth rate of unsuitable urban area, baseline 1: environmental suitability vs. four selected scenarios.

advocacies by other scholars who found that while environmental resource consumption per capita was less in big cities than smaller settlements, the reverse held in sheer area of consumption (Rowe, 2011; Kim, 2012). However, how much bigger should big cities grow in areas and enjoy the favorable policies they have enjoyed so far since China's opening up in the early 1980s? To answer the question, we need to consider the density of urban growth. The Scenario Cellular Automata model, not unlike Lowry and other models, assumes the same density for all newly urbanized land parcels. For example, one urbanized parcel in Shanghai functions equally as one parcel in Suzhou in terms of population increase absorption. In reality, the parcel in Shanghai could take in more people with higher density. The assumption of equal density could undermine the ability of the parcel in Shanghai to accommodate more people per square kilometer. On the other hand, the land use policy in large cities of the Changjiang Delta region restricts the residential land development to an average Floor Area Ratio of two or less, while in many mid- to small-sized cities in the same region, the average Floor Area Ratio was set to three (Interview with local government officials in Tianfu New District, 2016). If this discrepancy of different Floor Area Ratio between different-sized cities continues to exist, then the large cities may lose their advantage of being much denser in the newly urbanized area. To sum up, the urban growth, the local land use policy, and the actual population increase all play a role in deciding how much bigger big cities should grow. To make an argument, for scenario 4, 'disaster prevention, plus development corridors', Suzhou grew 21.59 percent bigger in 2030 than in 2010. Parenthetically, the total allocations of hypothetical population among the four scenarios at a rate of 9,000 people per square kilometer, an average for city-wide density, is on the order of 15 to 45 million more inhabitants and a median of around 23 million more inhabitants, or about 90 million total for the study area.

To further support this claim, images of urbanization in environmentally unsuitable areas from scenario 2 and scenario 4, 2030, are put side-by-side in Figure 2. The spatial distribution of scenario 2, the image to the left, shows a cluster of unsuitable development near Suzhou toward Lake Tai. This is an area adjacent to the southern part of peri-urban Suzhou. Indeed, this condition appeared multiple times around larger cities in the region in scenario 2. In addressing the environmental issues of big city growth, peri-urban areas are one of the most critical areas requiring alternative in policy making.

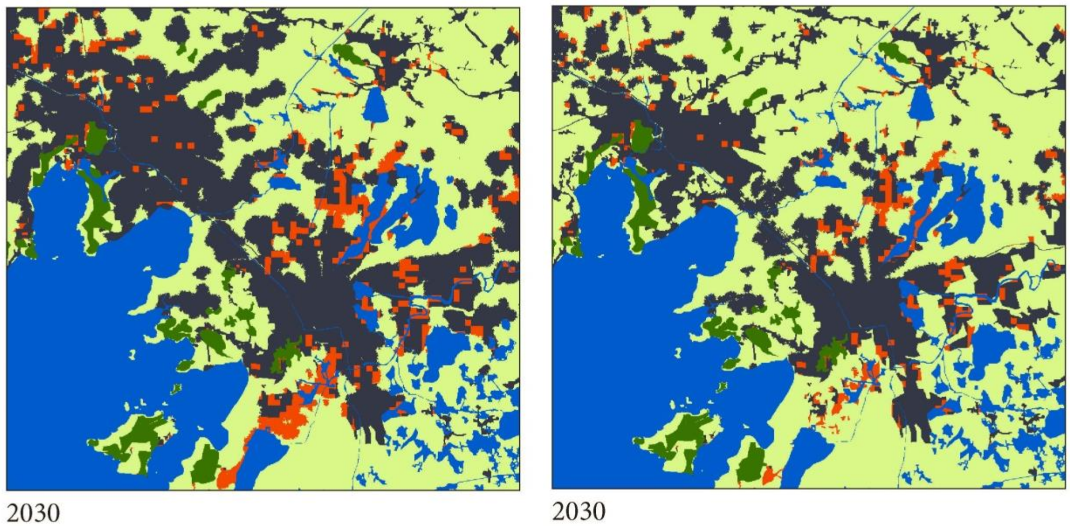


Figure 2. Left - baseline 1: environmental suitability vs. scenario 2: development corridors, plus big city growth; Right - baseline 1: environmental suitability vs. scenario 4: disaster prevention, plus development corridors, 2030.

2. What's the merit of disaster prevention?

Among four selected scenarios, scenario 4: disaster prevention, plus development corridors came out with the lowest growth rate, lower than one percent consistently throughout the years. One of the explanations is the disaster prevention restricting growth areas cover a large portion of the Changjiang Delta Region. Thus, the scenario provided less urban growth opportunity than the other three scenarios. The result of future urban growth prediction was also the slowest and had the least newly urbanized land parcels among four selected scenarios. To take a closer look at the disaster prevention restricted areas, many of them overlapped with environmental sensitive regions along the coastlines, scenic areas around Lake Tai, and other environmentally unsuitable areas. This further explained the low rate of annual growth rate of unsuitable urban area.

In general, human settlements in close proximity to disaster prone areas often lead to tragedy and even catastrophic events with severe consequences, as stated earlier. The rescue, restoration, and relocation consume disproportionally high socioeconomic resources. The aftermath can also bring long term disabilities and diseases to the affected population. If simply following the disaster prevention, plus development corridors urban growth policy can produce an urban form that optimizes the environmental resource conservation and prevents urban development from encroaching into environmentally unsuitable areas, then it seems to be a reasonable plan to be pursued in regional urban growth policy making.

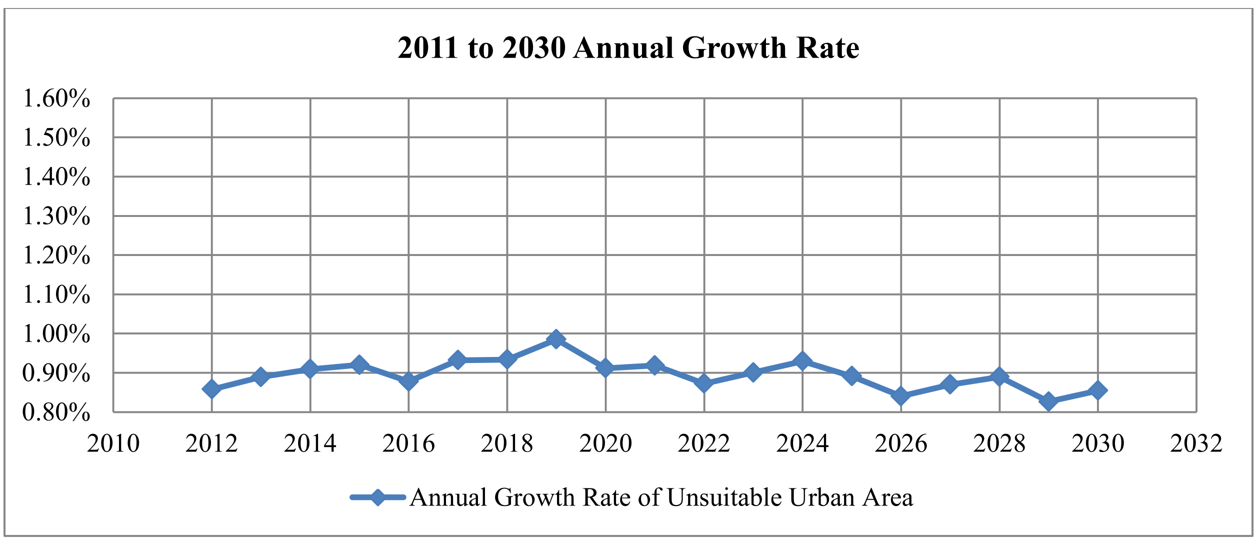


Figure 3. Annual growth rate of unsuitable urban area for scenario 4: disaster prevention, plus development corridors, reproduced from earlier graph with adjustment to the y axis.

3. Does ‘good’ urban development policy induce good urban form?

In Figure 2, the image to the left, prediction of scenario 2: development corridors, plus big city growth, exhibits further urban growth than the image to the right, prediction of scenario 4: disaster prevention, plus development corridors. In fact it is the most urban growth of all the scenarios. The urban form of Wuxi, in scenario 2, expanded to the western shore of the lake and connected the previously sporadic settlements in all directions, especially with strong growth along the transportation corridor to the northeast. It is worth noticing that the green park reservation areas are the most affective force stopping the urban expansion of Wuxi. The model simulated an urban growth pattern for one of the larger cities in the Changjiang Delta region that the urban sprawl happened in all directions with no natural barrier. This outcome also resembles the pattern of many cities around the world developed with no strong influence of 'good' urban growth policies[1]. In the planning of future regional urban growth, among the innovative concepts such as 'sponge city' and 'healthy city' which provides guidance for the 'soft infrastructure'[2], some conventional concepts, including restricted zones, green belts, and development corridors that focus on physical infrastructures, should be emphasized.

The relationship between policy orientation and urban form can be further elaborated with the comparison of correlation coefficients between economic performance and four selected scenarios and cultural amenity and four selected scenarios. In Figure 4 of economic performance, as expected, all four scenarios have exhibited a decreasing rate of correlation, since none of the scenarios directly incorporated economic performance of cities. In Figure 5 concerning cultural amenity, the results of the correlation coefficients among the four scenarios were less uniform. In scenarios 1 and 3, the curve shape followed a horizontal parabola and the general form equation being y is proportional to the square root of x. It revealed a positive correlation between cultural amenity and urban growth. In scenario 2, the parabola form was ending with a drop around 2023.

[1] A 'good' urban growth policy, takes the form of constraining, or re-directing, or both, spontaneous urban growth with regard to environmental and other indigenous conditions.

[2] Sponge city is an ecologically friendly alternative to urban sprawl using design strategies to solve urban issues without retrofitting physical infrastructures. Healthy city is a term used in public healthy and urban design to stress the impact of policy on human health. It is derived from a World Health Organization initiative. Both terms are emphasizing city's soft infrastructures in lieu of physical infrastructures.

It revealed that beyond 2023, the correlation changed direction and started to be negative. In the long term, if big city growth was promoted, then the cultural amenity should also be considered as part of the urban growth policy. In scenario 4: disaster prevention, plus development corridors, the correlation was negative throughout the years studied. It appears that cultural amenity should be emphasized equally in the cities that currently lack of such features.

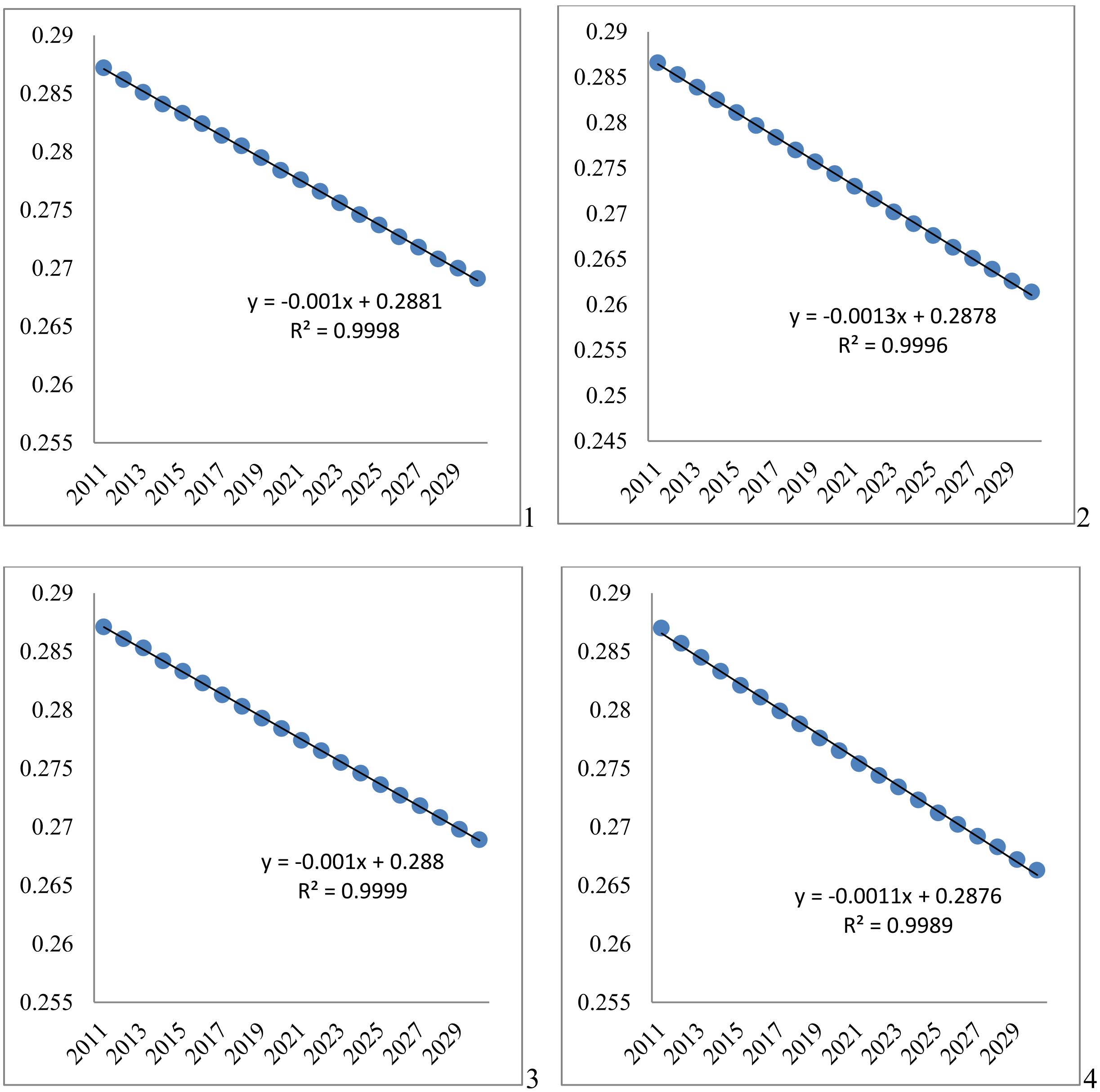


Figure 4. The comparison of correlation coefficients between baseline 2: economic performance and four selected scenarios, 2011-2030.

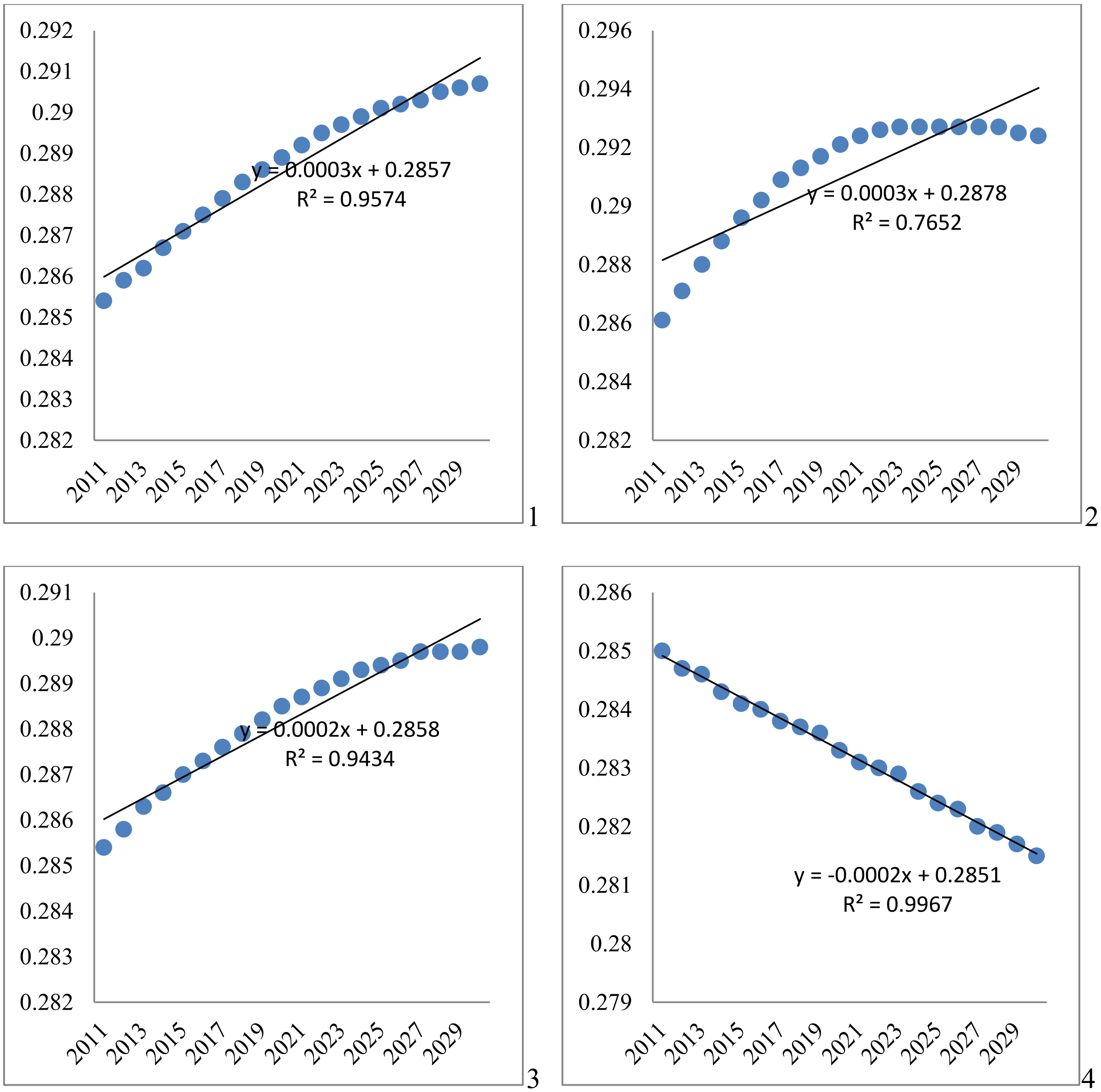


Figure 5. The comparison of correlation coefficients between baseline 3: cultural amenity and four selected scenarios, 2011-2030.

4. How to interpret rank orders and improve regional urban network efficiency?

Ranking of cities and towns based on economic performance was plotted in Figure 6. Different from Zipf's law, a trendline, in place of a 45 degree line, was used to evaluate the categories of the cities and towns. The trendline is more case specific and reveals the distribution pattern within the study region. As such, the tier one cities are the top six above the trendline, they are: Shanghai, Nanjing, Hangzhou, Suzhou, Ningbo, and Wuxi. From the seventh place, namely Changzhou, to around 28th place, namely Shangyu are tier two cities. Tier three included cities from Fuyang ranked 29th to Xiuzhou ranked 58th. The last few cities belonged to tier four. The ranking revealed the economic growth power house of the top six cities, the relatively underdeveloped tier two cities which can very well be improved, and a group of moderately economically overdeveloped tier three cities. Different urban growth policies can interpret this ranking in their own ways: tier one cities should grow bigger if regional centering is the goal for regional urban network, tier two cities should grow stronger to adapt to the trendline if a well-balanced category of cities appears on the priority list, or tier three cities should stay where they are since the Changjiang Delta Region has always had economically strong smaller cities and towns.

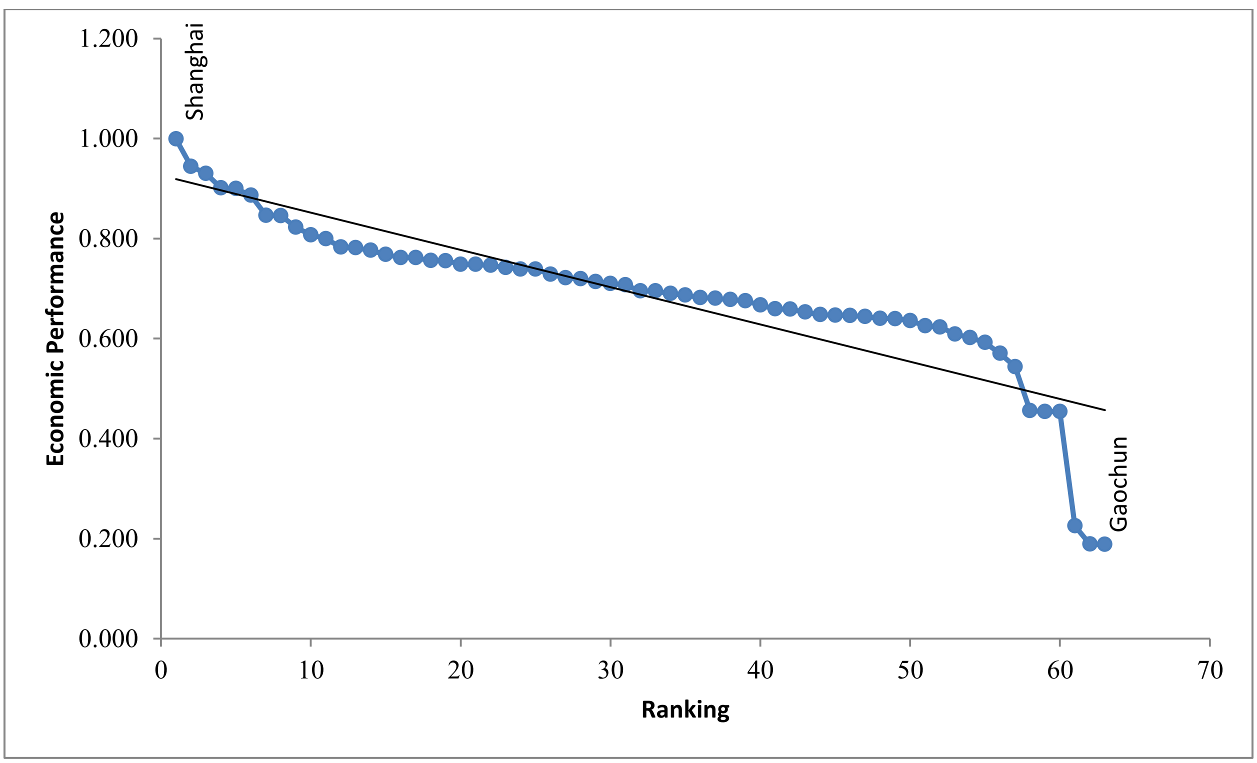


Figure 6. Ranking of cities and towns based on baseline 2: economic performance.

Figure 7 showed the ranking of cities and towns based on cultural amenities. Similar to the ranking for economic performance, the trendline approach was applied. Tier one cities are the top five: Suzhou, Nanjing, Wuxi, Hangzhou, and Shanghai. Tier two cities are Ningbo, Shaoxing, Zhoushan, Yangzhou, and Zhenjiang. From the eleventh place, Changzhou to 47th place, Jurong are tier three. Qidong and the rest of the cities and towns are considered tier four. Both tier one and tier two possessed affluent with cultural amenity in their cities. Most of the tier three cities were under the trendline thus relatively lacking in cultural amenity according to their rankings. Tier four, again, was moderately overloaded with cultural amenity. Similar to economic performance, the interpretations can vary according to urban growth policies in play.

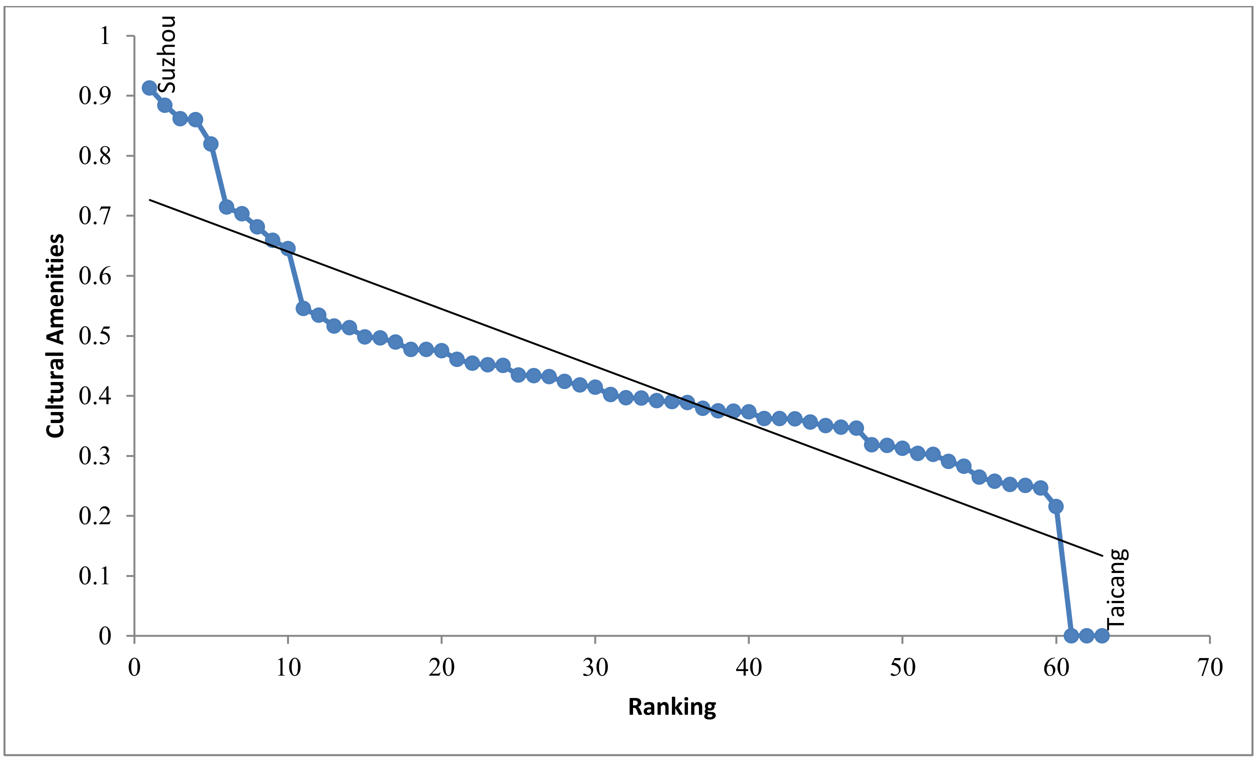


Figure 7. Ranking of cities and towns based on baseline 3: cultural amenities.

Chapter 6. Contributions and applications

This chapter summarizes the research contributions of the thesis and potential applications in future research in regional urban network and spatial analysis. It starts with revisiting the urban growth models, followed by a reinstatement of findings on data collection techniques, as well as takeaways for well-performing urban networks. The chapter then reexamines the contributions of this research and discusses future investigation opportunities and implications for further research.

1. Scenario Cellular Automata and its applications.

Compared with the Lowry model, the Scenario Cellular Automata model didn't project rapid growth along the Nanjing-Hangzhou corridor. The Lowry model singled out areas along this corridor by prohibiting urban growth in the rest of the region. However, the Scenario Cellular Automata model took into consideration of urban growth in all development corridors simultaneously without discriminating one over the others. Thus the result of the Scenario Cellular Automata model seems to more closely simulate realities. First, the creation of large cities along development corridors is very unlikely to happen, nowadays. The high-speed rail from Nanjing to Hangzhou was put in place for better connections not for stops in between. Indeed, this is only one of the advantages using Scenario Cellular Automata model. There are also other advantages stated in the earlier chapter, including yearly consecutive prediction and the effects of a large number of Monte Carlo Simulation runs. The Scenario Cellular Automata can also be used in wide applications to test urban policy on future growth patterns at regional, as well as urban scales with close monitoring of single or multiple variables. It also forward projects outcomes, rather than back projecting like the Lowry model.

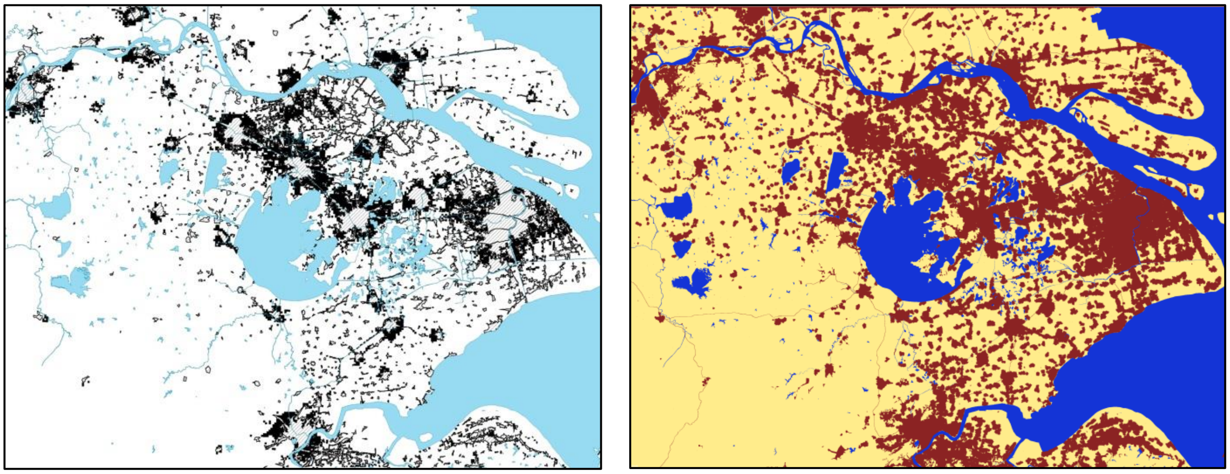


Figure 1. Comparison between projected results by Lowery model and Cellular Automata model. Urbanization projected by a Lowry model (left) and by a CA model (right), 2040.

A tool box, built in 'cygwin terminal[3]' and linked to ArcMap, was developed here to perform similar modeling processes as a SLEUTH model, but with replaceable variables tailored to specific research goals. The tool box streamlined data preparation, model prediction, and result analysis and appears to have made a contribution to the field of spatial modeling.

2. The urbanization rate of land consumption is relevant.

Conventionally, urbanization rates of population are used to describe the urban conditions of nations. It has become an international standard to make comparison among regions and countries. The United Nations World Urbanization Prospects, for example, is one of the commonly referred sources of rankings for urbanization of population. The advantages of such a measure include: first, population, by treating people as commodities, is universal. It is unlike 'household' or any other unit, which may vary by culture and ethnicity. Second, through census

[3] Cygwin is a large collection of GNU, an operating system, and Open Source tools which provide functionality similar to a Linux distribution on Windows.

collection that occurs regularly in many country and sub-country level entities, the available data are relatively reliable. However, the limitation of using population to evaluate urbanization discounts the urbanized land itself, which provides most of the resources supporting urbanization. The advantages to evaluate urbanization rate using land resources include: first, flexibility. The size of land parcels can be large or small, depending on the research goal and methodology applied. Second is consistency. The administrative boundaries may vary by size, but the land parcel can be divided to equal sized rectangular shapes for accounting purposes. Third, and maybe the most important, is 'spatiality'. Unlike the urbanization rate of population, which is largely constrained to the administrative boundaries, the urbanization rate of land consumption can be measured to the size of specific land parcels and reveal the spatial distribution at a much finer scale. Parameters that could relate to urbanization rate of land resources include but are not limited to Gross Domestic Product, road length, and other infrastructure.

3. Data became widely available and analytical techniques improved.

As the computer calculating capacity increases astronomically and the development of remote-sensing technique evolves, accompanied by enhancing satellite image resolutions, the study on land-use change and spatial distribution became more sophisticated. Yamaguchi, Chen, Seto, among other scholars, have taken these opportunities to advance the research in the relevant field (Chen, et al., 2012; Srinivasan, et al, 2012). 'Big data', as the growth of and digitalization of global information storage capacity increases exponentially, the volume, velocity, and variety of information assets enable enhanced decision making (Beyer, 2011). The application of big data in regional urban study and urban growth prediction allows the study of the entire population, i.e. a collection of people, items, or events about which to make inferences, instead of sampling a subset. In this research, the 350 kilometer, east to west, by 250 kilometer, north to south, study area of the Changjiang Delta Region was divided into 8,750,000 100 meter by 100 meter land parcels. The environmental suitability, economic performance, and cultural amenity information were then distributed to these over eight million data points, covering the entirety of the study area, without sampling. This operation, in many ways, qualifies as an application of big data research. Looking ahead to the future, both technical and methodological improvements can transform the filed in urban growth research. For example, quantum computation using superposition and qubits can alter the urban growth modeling technique and enhance the simulation algorithms to the extent of increasing calculation speed beyond our imagination.

4. Revelation of a well-performing urban network in the Changjiang Delta Region.

At the scale of a regional urban network, a single well-developed primate city, will likely not lead the network to its optimal condition. Similarly, a uniformly developed group of cities will not perform well together either. The question is how to make a well-performing urban network in the Changjiang Delta region and through what channel to make it meaningful? Based on the previous analysis, a few factors stand out as important: first, the growth rate of each city and town and the balance among them comes to mind. Second, the development corridor between Nanjing and Hangzhou seems to be limited. The growth won't be as substantial as the Nanjing-Shanghai and Shanghai-Hangzhou corridors because of the small growth base, both in terms of economy and population. Unless there are significant cities appearing on the map in the future, which is not very likely, the Nanjing-Hangzhou corridor will stay relatively undeveloped.

Third, comparisons among the scenarios provide instructive results with regard to unsuitable land development patterns.

In Figure 3, a well-performing urban network in the Changjiang Delta Region is depicted, based on scenario 4, with a system of large, medium, and small-sized cities and towns. The large urban settlements are represented in red, medium-sized cities are highlighted in orange, and the areas for smaller towns are in light orange. The non-performing towns in terms of economic performance were represented with diagonal hatch in black lines. The development corridors, including both highway system and the rapid train system are shown in bold red lines, and the national roads in thinner red lines. The Grand Canal, a historical waterborne development corridor is represented in blue lines. Fault lines in the region were also shown with light grey color. Four clusters of urban settlement within the Changjiang Delta's regional urban network appeared to be significant. First, the Shanghai metropolitan area, including satellite towns within the administrative boundary of Shanghai and also Kushan, a town that is located to the west of Shanghai and became part of the urban cluster as Shanghai expanded. This cluster is the economic engine for the entire region, if not for the whole nation. The potential urban growth is backed up with migrants from all parts of China and many foreign countries. The available land was also increased as Chongming Island, the second largest island of People's Republic of China, acquired road connections to Pudong to the south and Qidong to the north. The ongoing land reclamation also contributed to the supply of developable land area. Second, there is the Suzhou-Changzhou-Nantong development triangle. This cluster is composed of many medium-sized cities with strong economies and dense peri-urban areas. In it, Suzhou, Wuxi, Changzhou, Jiangyin, Zhangjiagang, and Nantong are all well-integrated together with transportation networks as well as cultural linkages. To the east, the boundary between Suzhou and Kunshan was drawn along the fault line. To the Southwest, the cluster extended to Yixing, connecting to the Nanjing-Hangzhou rapid train corridor. To the north, the bridges between Nantong and Changshu, and Jiangyin and Subei weave these areas even closer than before. Rudong, was left out of the cluster because its remote location from the center of the area and the pull of Hai'an to the north. If the Shanghai metropolitan area is tthe 'dragon head', then this triangle cluster defines the distinct characteristic of the region. Third, there is the Nanjing-Zhenjiang-Yangzhou growth zone, which resembles the shape of the 'blue banana' of Europe but at a smaller scale. In this zone, the major urban development area sits on both sides the Changjiang. They are connected by seven cross-river bridges, which is one of the densest set of links for the entire river. Wuhu and Dangtu, both appeared in the map, were eliminated from the Nanjing-Zhenjiang-Yangzhou zone, because of their tighter connections with Hefei and other cities in Anhui Province to the west with the two cross-river bridges. Fourth, there is the Hangzhou-Shaoxing-Ningbo bay rim growth cluster. It marks the southern end of the Changjiang Delta Region, before the topography becomes hillier and geographical as well as culturally separate from southern Zhejiang Province. The outward connection of this cluster is more promising through the cross-bay bridges connecting Cixi and Shaoxing to the northern part of Zhejiang Province and Shanghai. Figures 4 and 5 represent the node-link diagrams of the spatial distribution of urban clusters in the Changjiang Delta Region. Figure 6 summarizes the rankings and tier categories of the cities and represents the basis for the apportionment of large, medium and small cities and towns in figures 3, 4 and 5.

In summary, the six large cities, starting with Shanghai are in the first tier. The following nineteen cities and towns, starting with Changzhou are next in line by rank order of economic and other references but are 'underperforming' with regard to these potential. They are identified in figure 5 by the orange dots and network links in order to show potential future outcomes with sufficient attention to each and to further infrastructural developments among them. This last point is also reinforced by the appearance of the small towns starting with Shaoxing as being relatively independent. A situation that is less likely to persist with structured infrastructural development among the second tier of cities starting with Changzhou and extending downwards through the remaining rank ordering of cities. Those at the tail end of the distribution, starting with Xiuzhou, appeared to be in decline. In short, with developmental tension shifted to the nineteen tier two cities, a well-balanced network of urbanization seems likely to emerge with superior performances across the baseline conditions. One upshot of this outcome will be the parallel banding of urban networks largely perpendicular to the east-west growth corridors, in contrast to what seems to be conventional wisdom about the region's development.

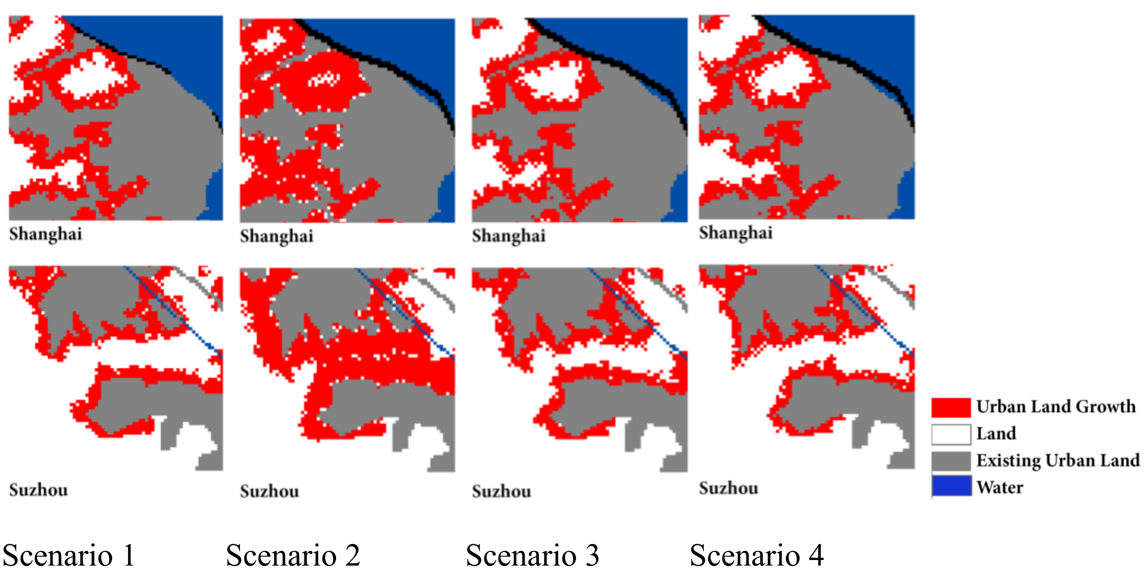


Figure 2. Comparisons among four selected scenarios with regard to unsuitable land development patterns. From left to right are scenario 1: development corridors, scenario 2: development corridors, plus big city growth, scenario 3: ecological system concern, plus development corridors, and scenario 4: disaster prevention, plus development corridors.

Figure 3. A well-performing urban network in the Changjiang Delta Region, scenario 4: disaster prevention, plus development corridors, 2030.

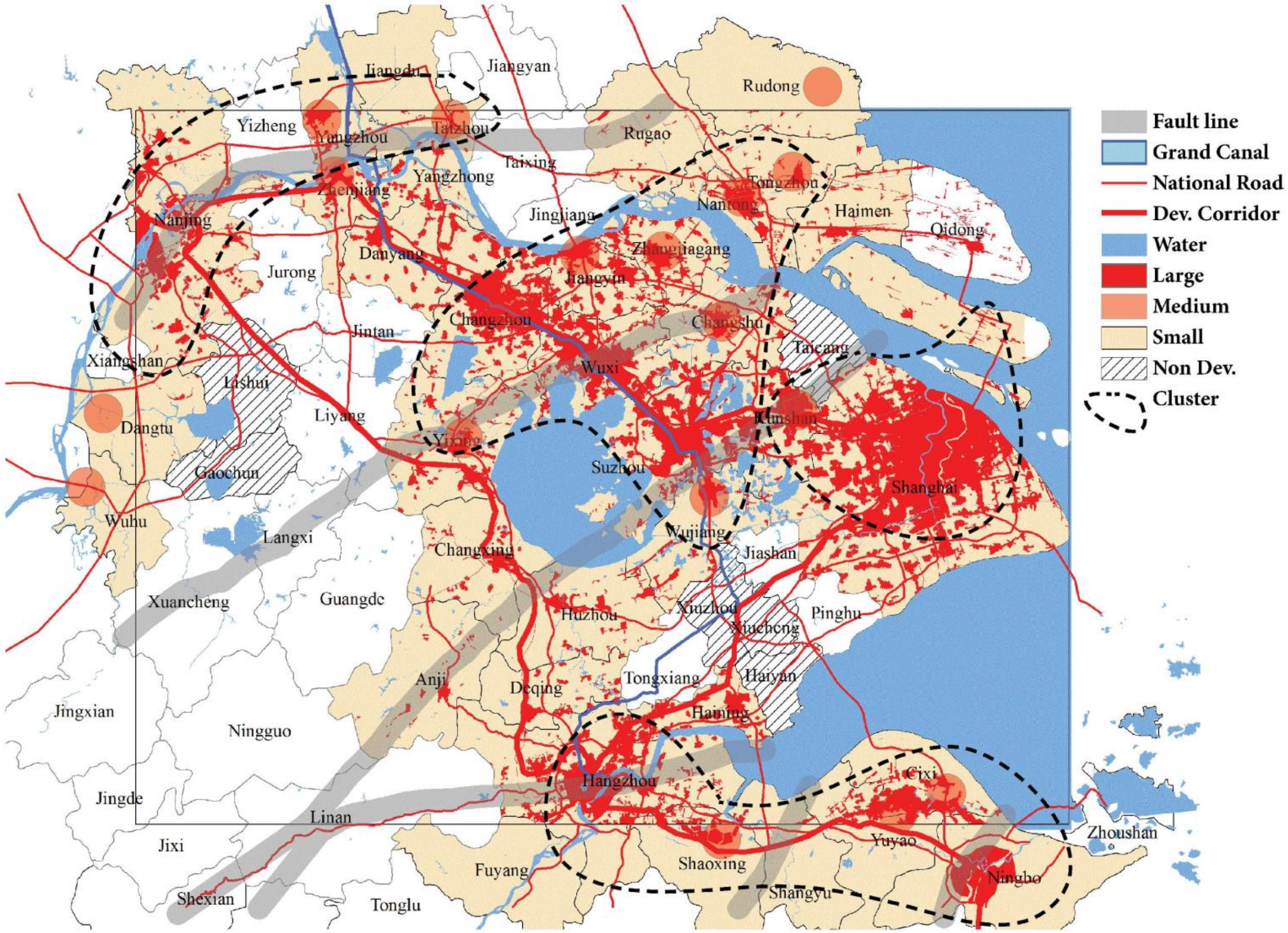
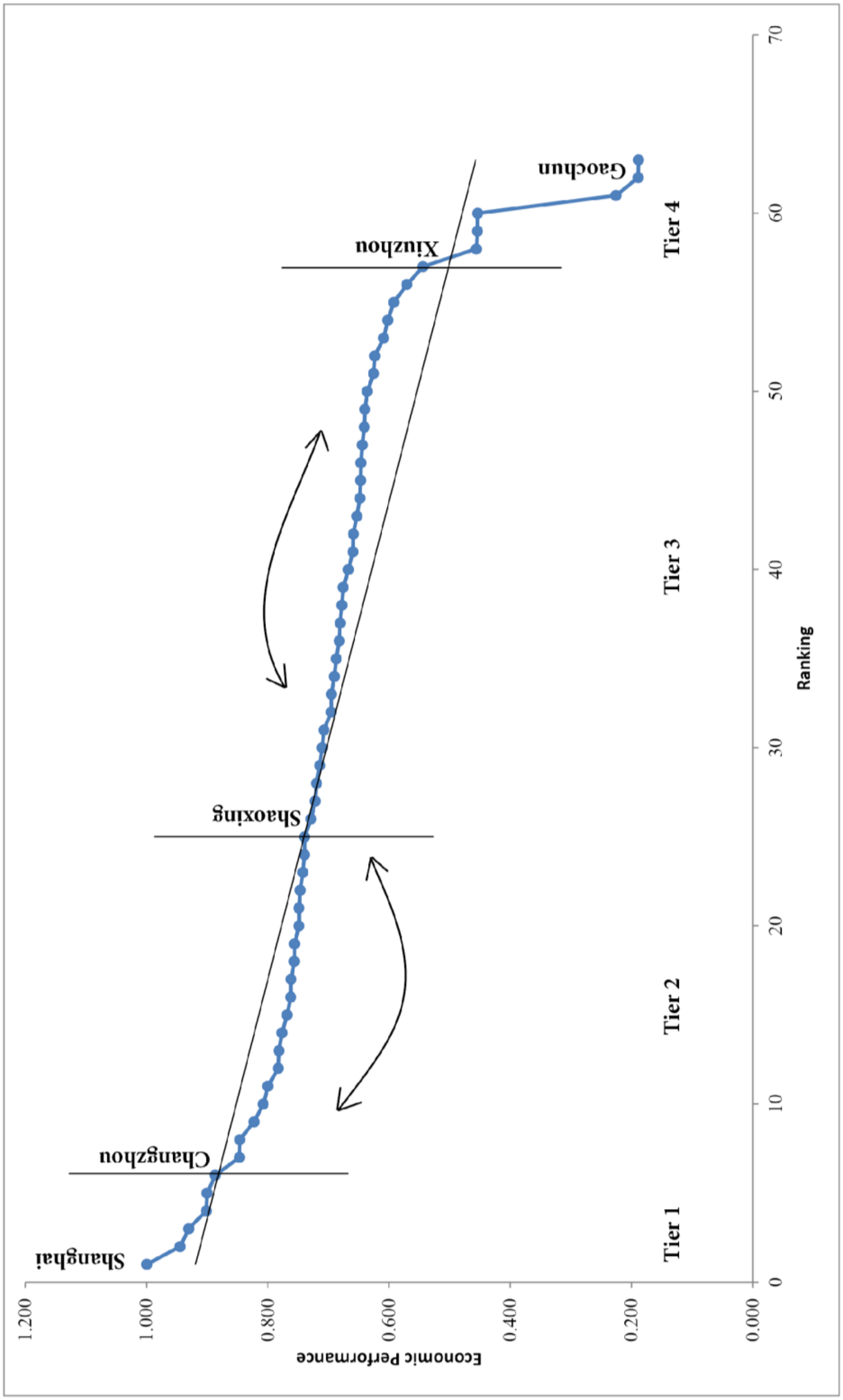


Figure 4. A well-performing urban network in the Changjiang Delta Region, node-link diagram, scenario 4: disaster prevention, plus development corridors, 2030.

Figure 5. A well-performing urban network in the Changjiang Delta Region, node-link diagram 2, scenario 4: disaster prevention, plus development corridors, 2030.

Figure 6. Rankings and categories of cities and towns based on economic performance.



Tier two cities are below the trendline, indicating that they underdeveloped. In contrary, tier three cities, mostly above the trendline, are well-developed.

5. Evaluate performance of urban networks.

One contribution of the research is quantitatively evaluating performance of urban networks. First, the establishment of scoring systems. It provided a platform to quantify the variables regarding performance of urban networks. For example, the Economic Performance Index and Cultural Amenity Index were both evaluated on a combination of weighted variables. Other examples including Urban Intensity could also be applied in the quantification of performance of urban networks. Second, the quantification of variables made it possible to run regressions. Short of causality per se, a regression model can be used to find out what are the influential factors of urban growth prediction and to what extent they are influencing the predicted pattern based on current available data, also a 'big data' gambit.

6. Interpretation of the changing pattern of urban growth.

a. Change of geometric shapes of growth

One of the distinct characteristics of spatial modeling using cellular automata is clear revelation of a geometric shape to increments of settlement growth and change. In fact, it can be manipulated in a manner that allows timing approximately to one-year increments to be displayed. Resulting maps also bear striking resemblances to what appear to be relatively routine depictions of urban growth in the form of expanding or contracting areas of urban coverage. One important interpretative question that is raised by these depictions is the shape of urban change and what possible construals might be placed on such patterns. To date this is a poorly researched area of investigation, although some of what might be portrayed is suggested by a few studies. Among the 3,646 cities that have populations in excess of 100,000 in the year 2000 identified by the Lincoln Institute of Land Policy, Angel et al selected 120 cities to examine their key attributes of urban expansion (Angel et al, 2012). They are discrete spatial attributes including urban land cover, density, fragmentation, and compactness. This is not a complete list to describe the comprehensiveness of spatial urban attributes, as claimed by Angel et al, but they represent an overall picture of the urban expansion pattern from 1990 to 2000 and point of comparison for this study. The broader point here is that this study will seek to develop a systematic approach to characterizing shape changes and potential implications in urban land cover.

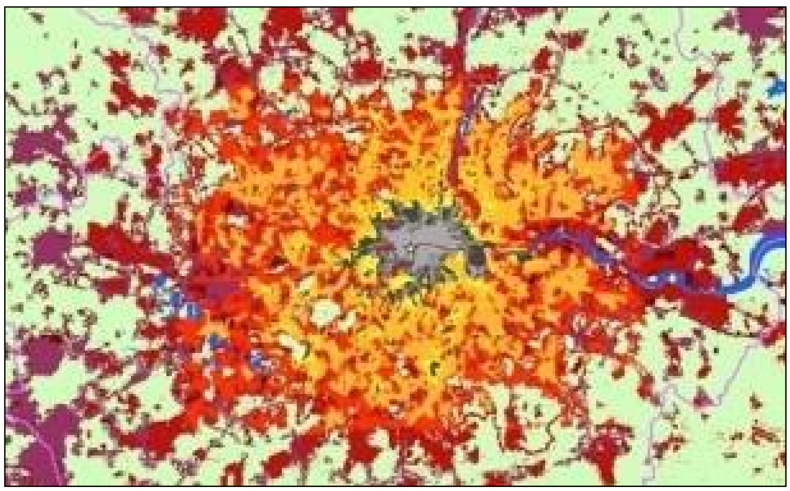


Figure 7: Urban expansion.

b. Environmental policy implications

One more or less certain outcome of modeling exercises will be an ability to assess changes with regard to baseline environmental land cover within the Changjiang Delta region. This baseline has already been developed, at least partially, in the form of a geographic information system with image data at one square kilometer grid cells[4] (Kim and Rowe, 2012). Spatial resolution of the cellular automata output with this database can readily be performed,

[4] This also provided a base for the 100 meter by 100 meter grid cells, which was applied to Scenario Cellular Automata models for urban growth prediction.

relevant important areas of resource loss calculated, and a measure of environmental performance, with policy implications, advanced.

7. Potential contributions.

In conclusion, first, while big cities should grow larger in order to minimize resource consumption per capita, a well-developed network of large, mid-sized, and small cities and towns will likely perform better by offering advantages of alternative life style diversity, more compact and intense development, less pervasive cover of non-urban-assets and lessened diseconomies of excessive scale and over population of particular cities. Second, the shape of incremental changes of patterns of urban spread can be seen to exhibit an underlying logic explicable in terms of dynamics such as rates of spread, infrastructural development, regulatory control and economic advantage. Further, continuous outward expansion can be put down to simultaneous growth pressures overcoming the shaping effects of particular factors, whereas, extensive linear expansions are likely shaped by particular features like infrastructure development and may even be seen to be undetermined.

The potential contribution of the research included: first, enhanced understanding of the Changjiang Delta region’s likely future patterns of urban development in particular and the behavior of urban networks of large, medium-sized, and small cities and towns in general. In these regards it was the medium-sized (tier two) cities that seem to require further accelerated development. Second, further testing of the applicability of Scenario Cellular Automata to produce computer modeling outcomes that can apply to ranges of policy decisions regarding patterns of urban settlement.

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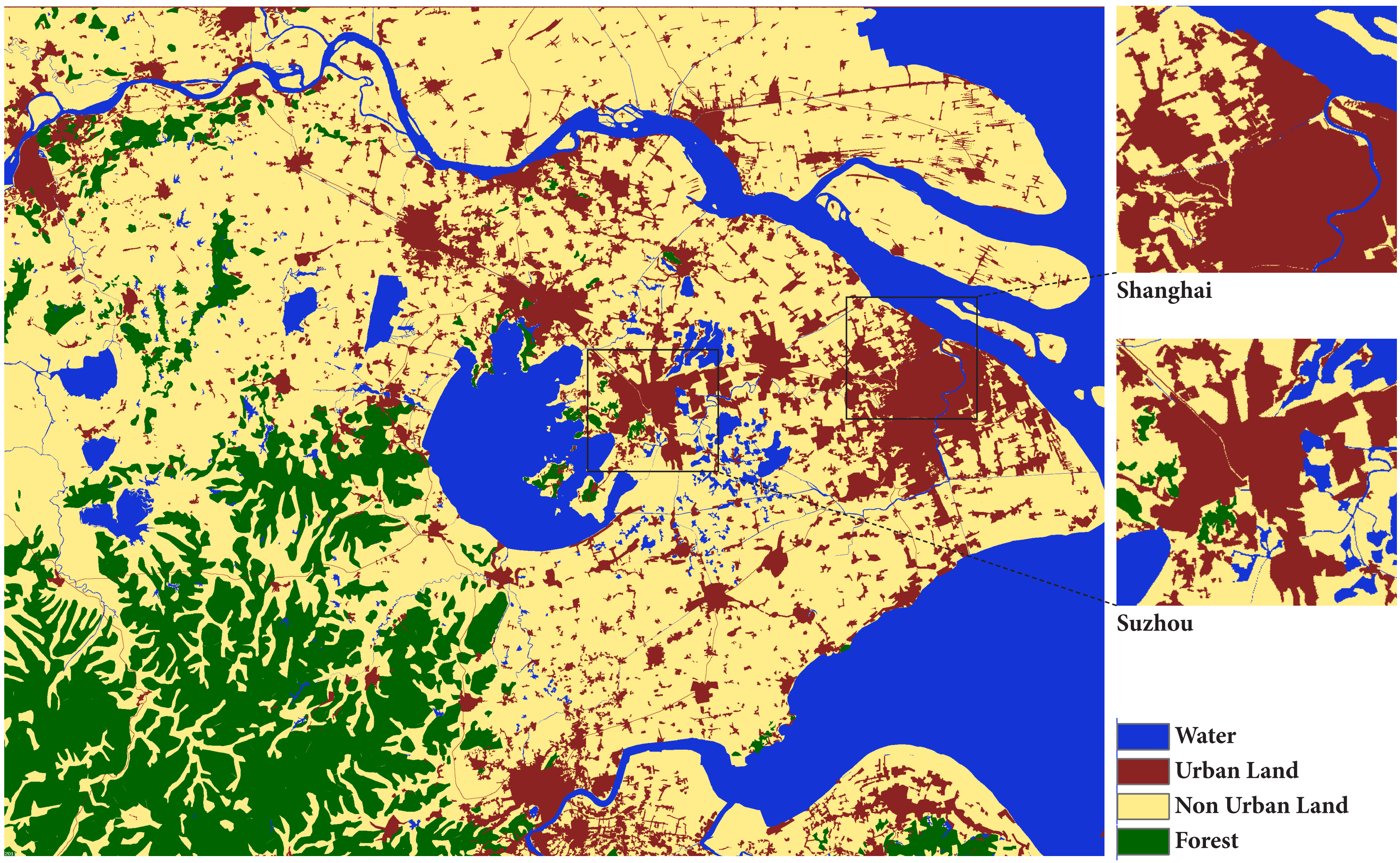
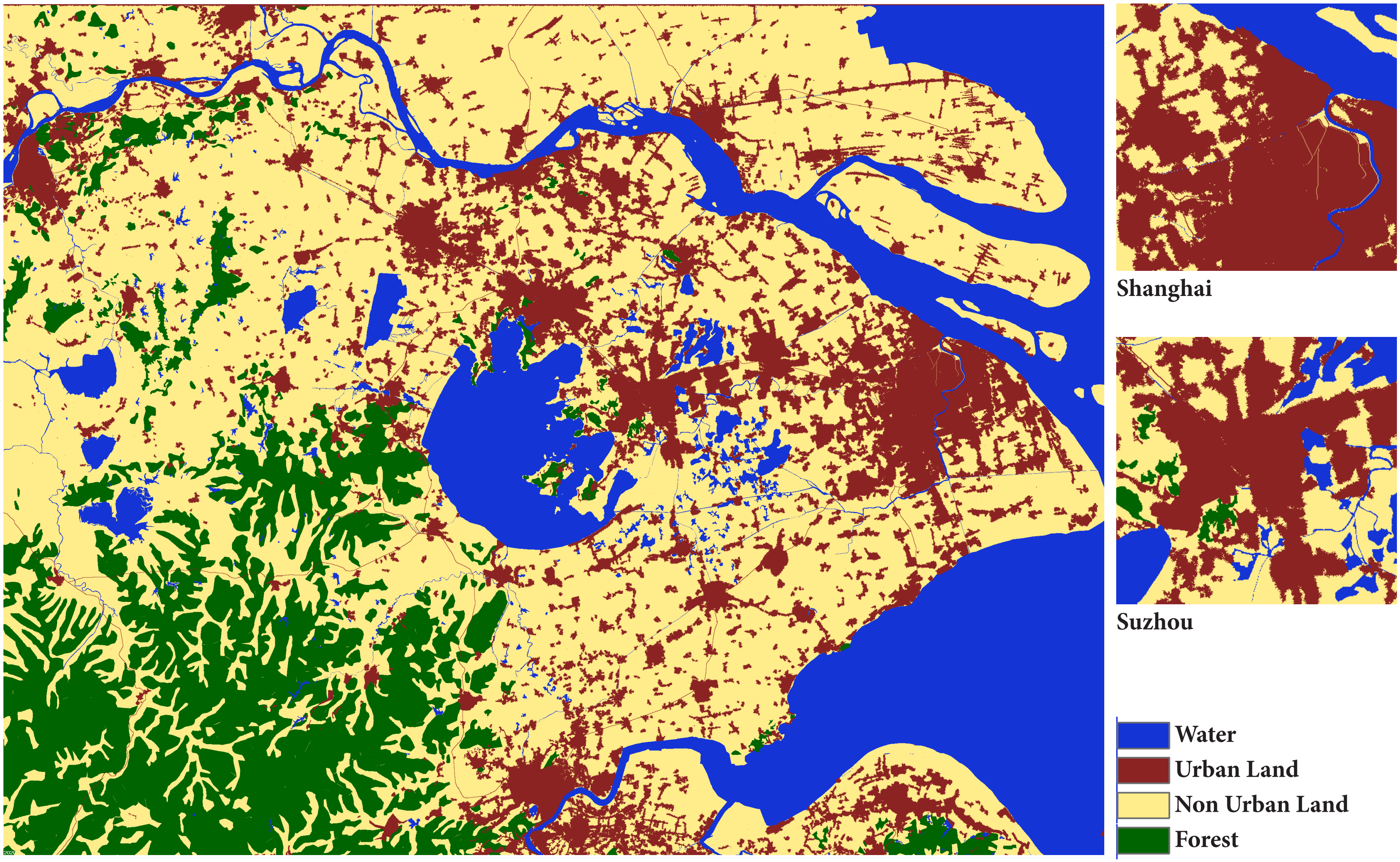
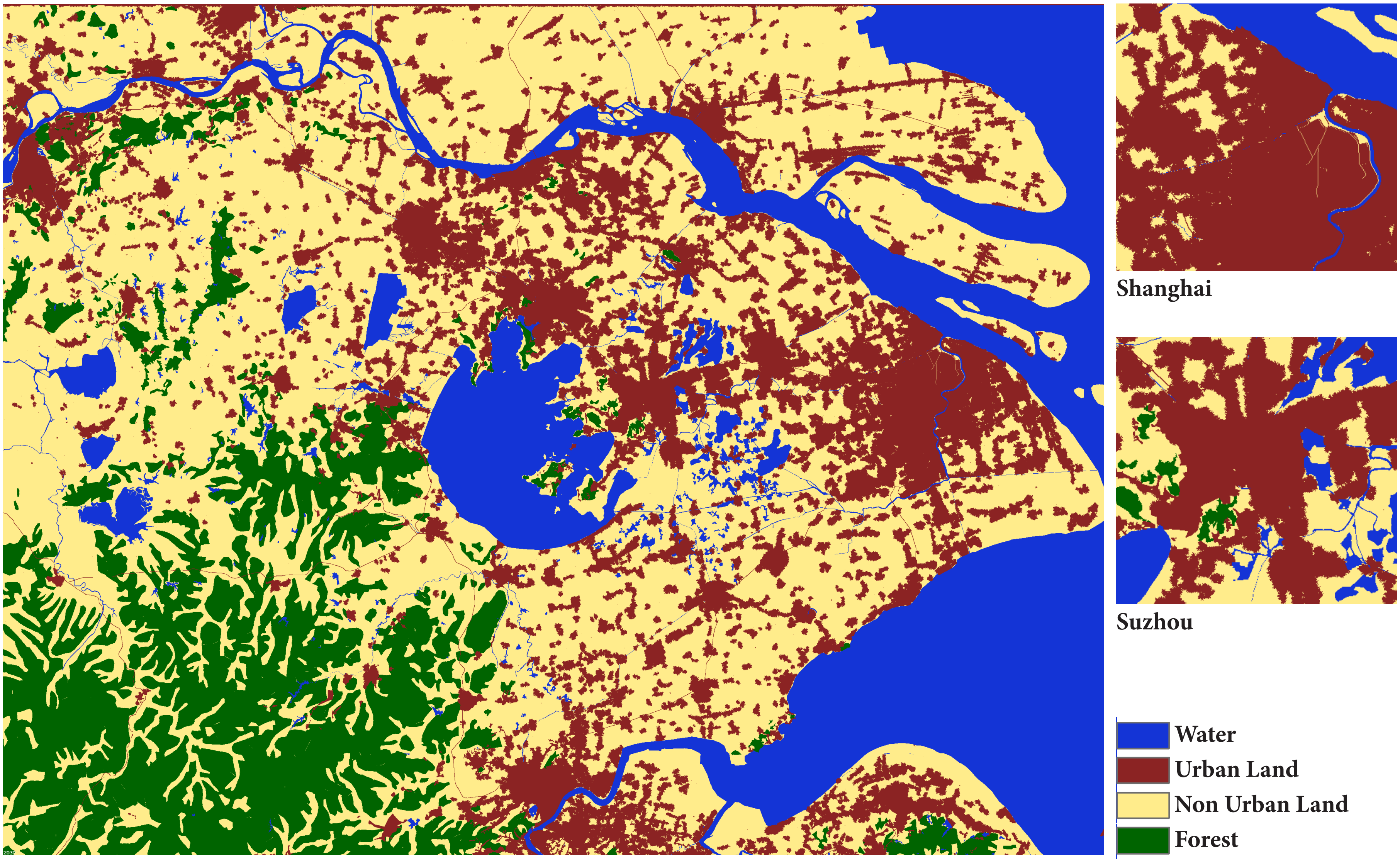
Appendix 1. Generic urban growth prediction for the Changjiang Delta Region. Cellular Automata model prediction, 2011.



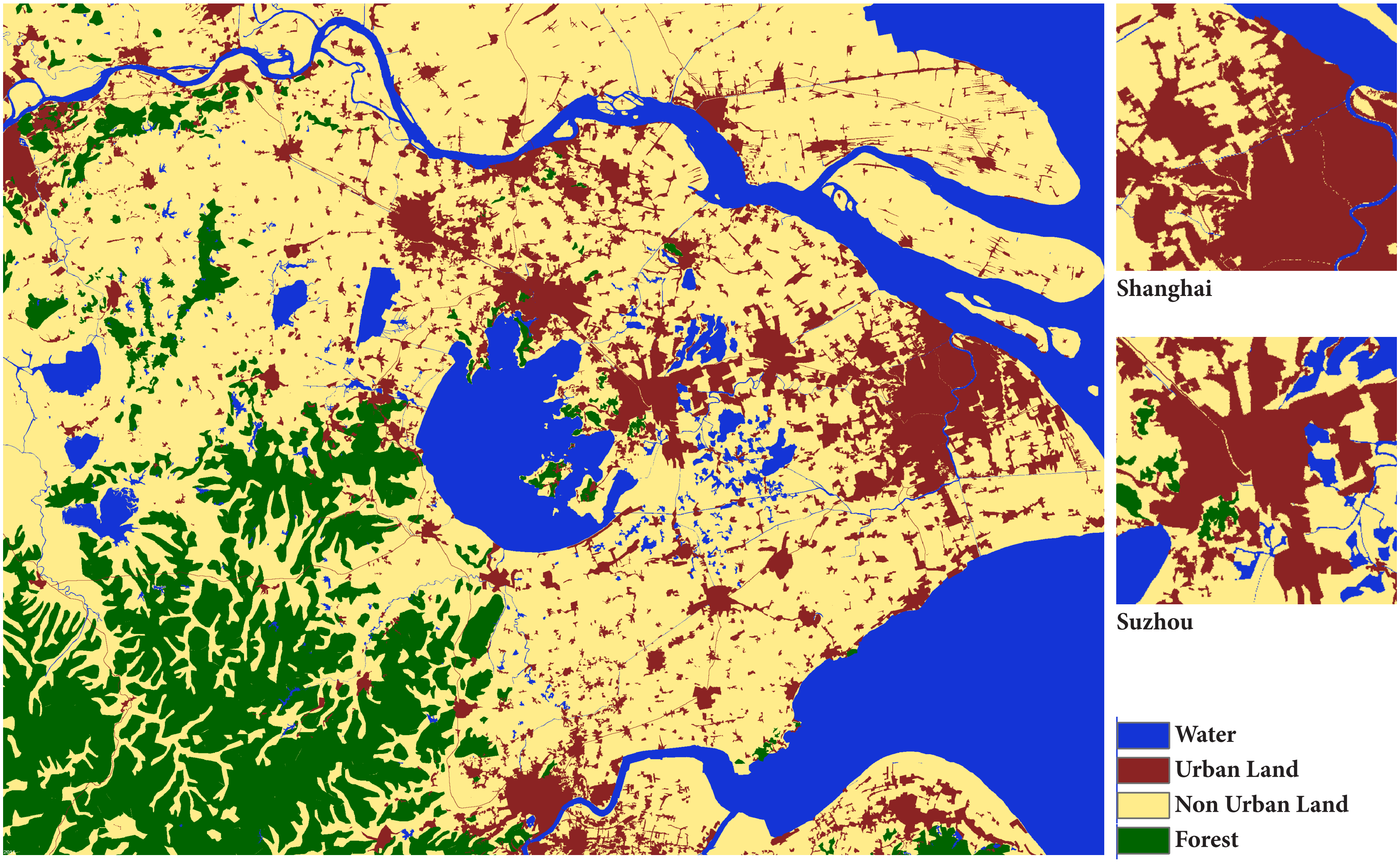
Appendix 1. Generic urban growth prediction for the Changjiang Delta Region. Cellular Automata model prediction, 2020.



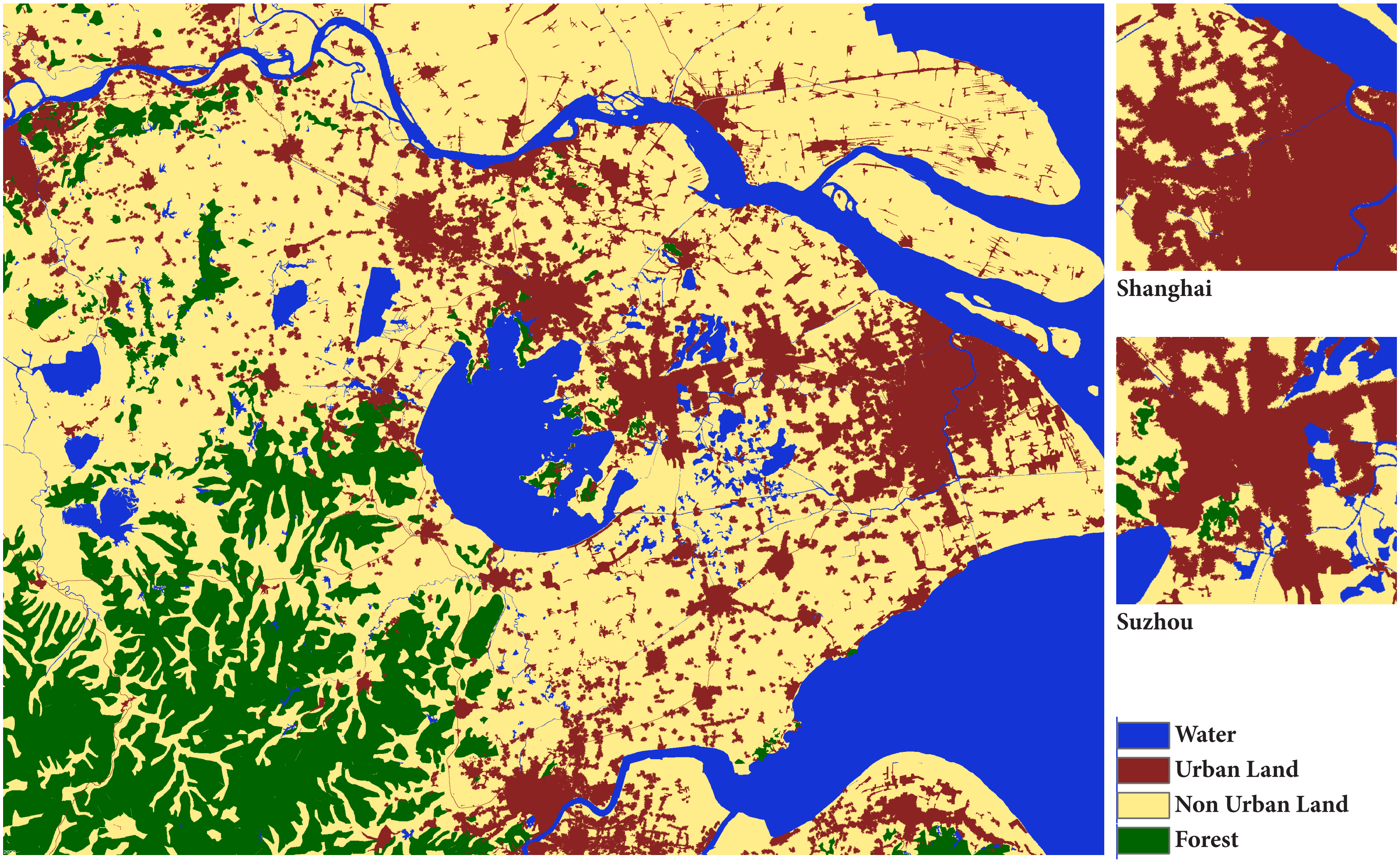
Appendix 1. Generic urban growth prediction for the Changjiang Delta Region. Cellular Automata model prediction, 2030.



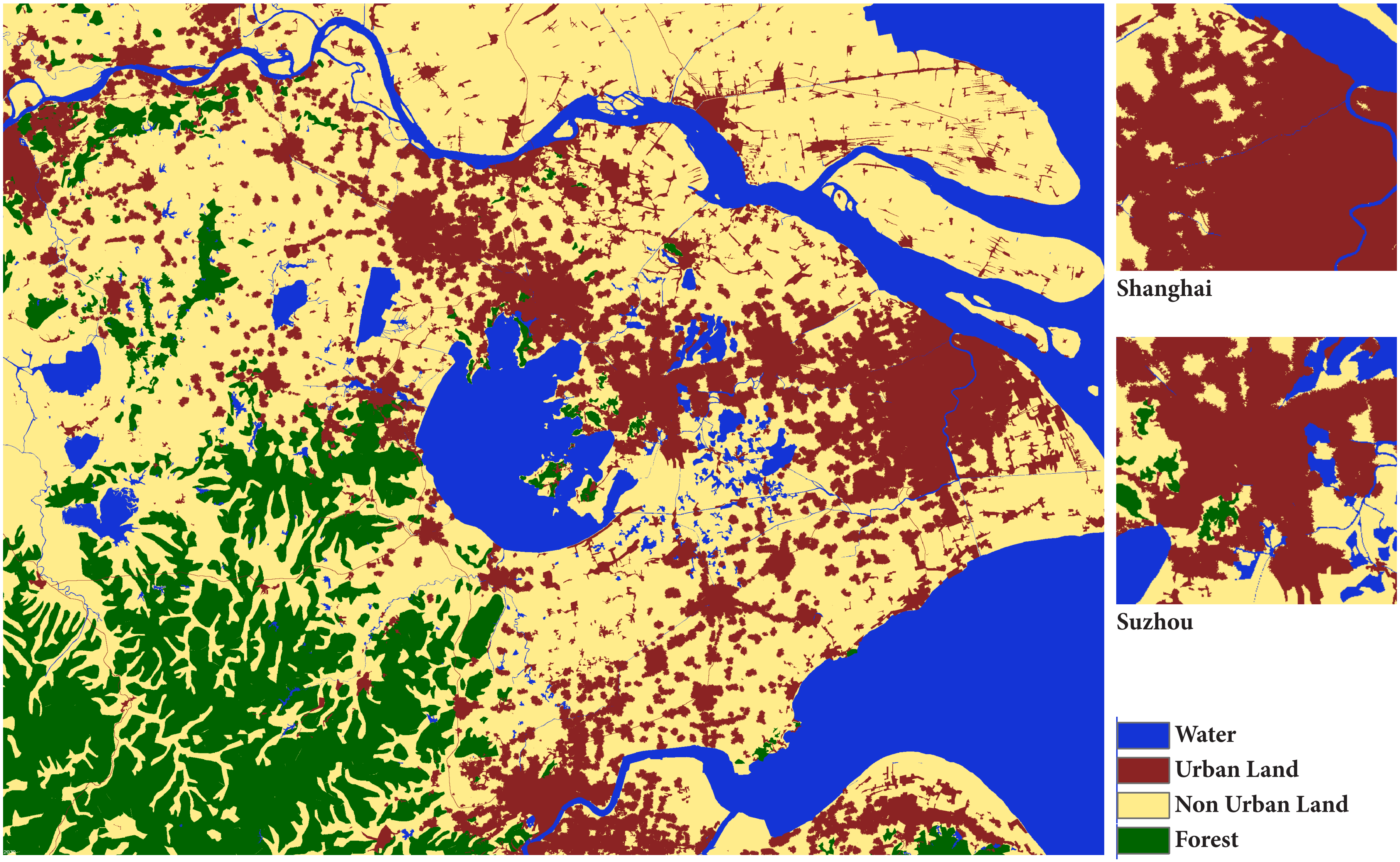
Appendix 2. Scenario 1: development corridors model prediction and analysis for the Changjiang Delta Region.
a. Scenario Cellular Automata model prediction, 2011.



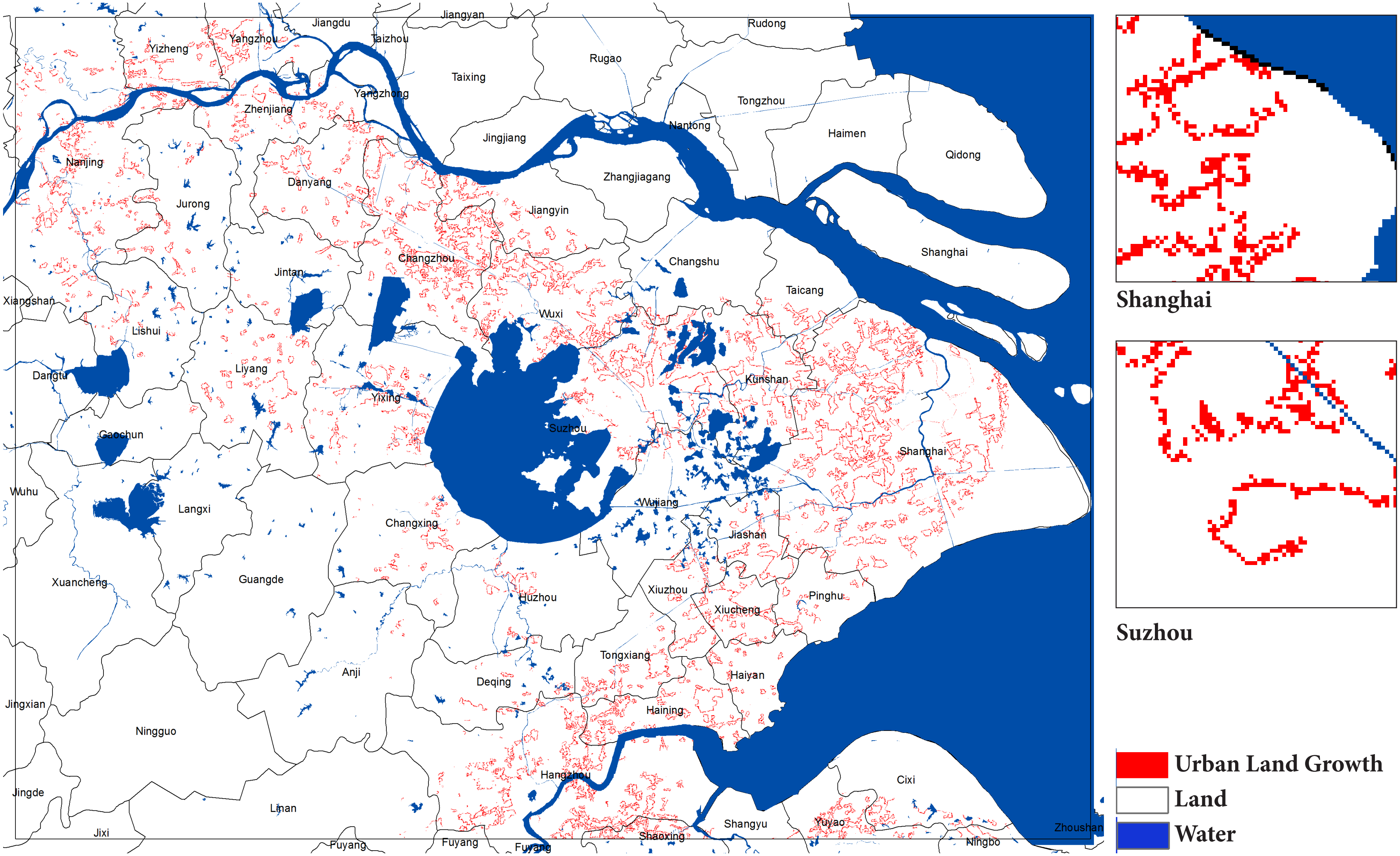
Appendix 2. Scenario 1: development corridors model prediction and analysis for the Changjiang Delta Region.
a. Scenario Cellular Automata model prediction, 2020.



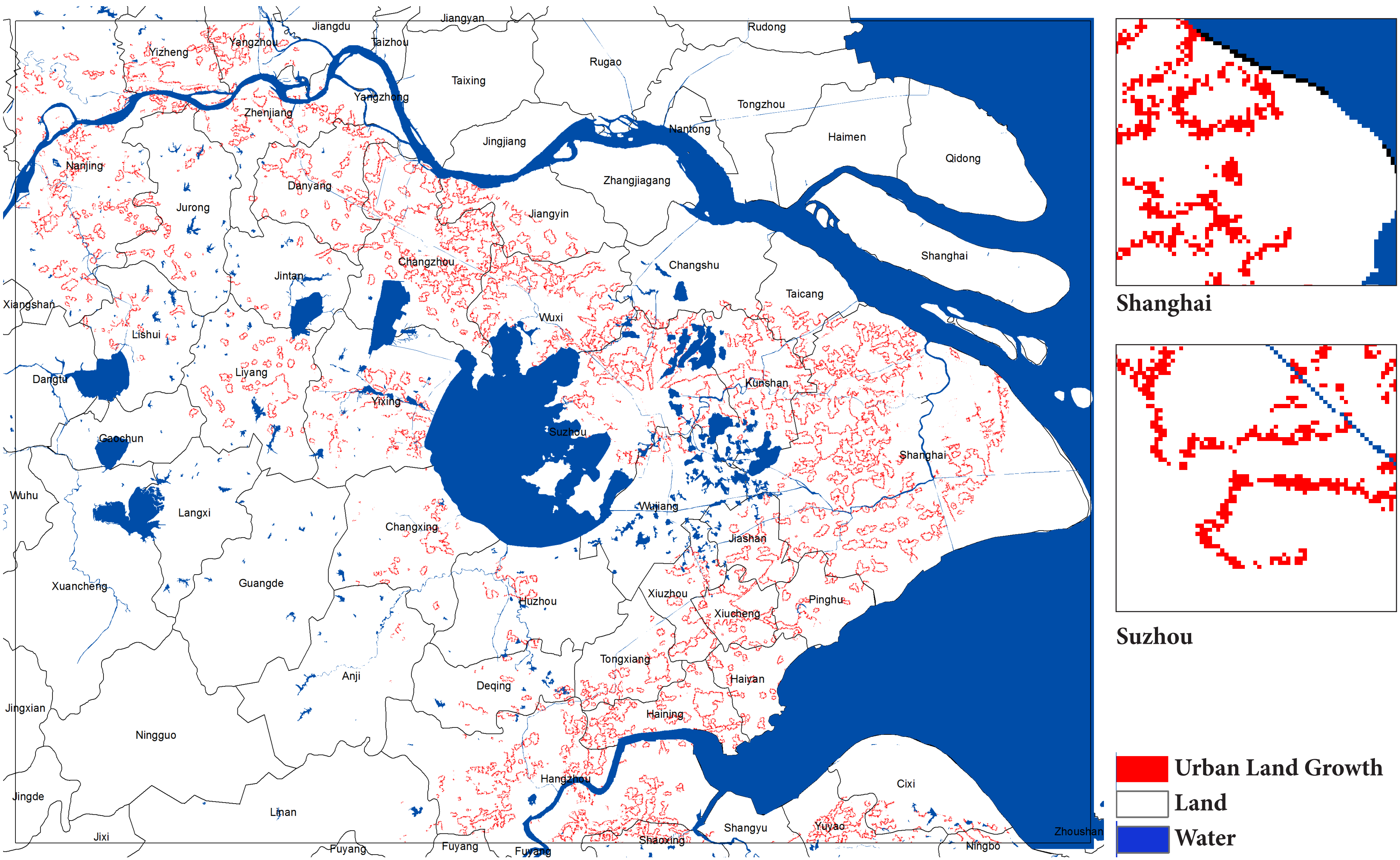
Appendix 2. Scenario 1: development corridors model prediction and analysis for the Changjiang Delta Region.
a. Scenario Cellular Automata model prediction, 2030.



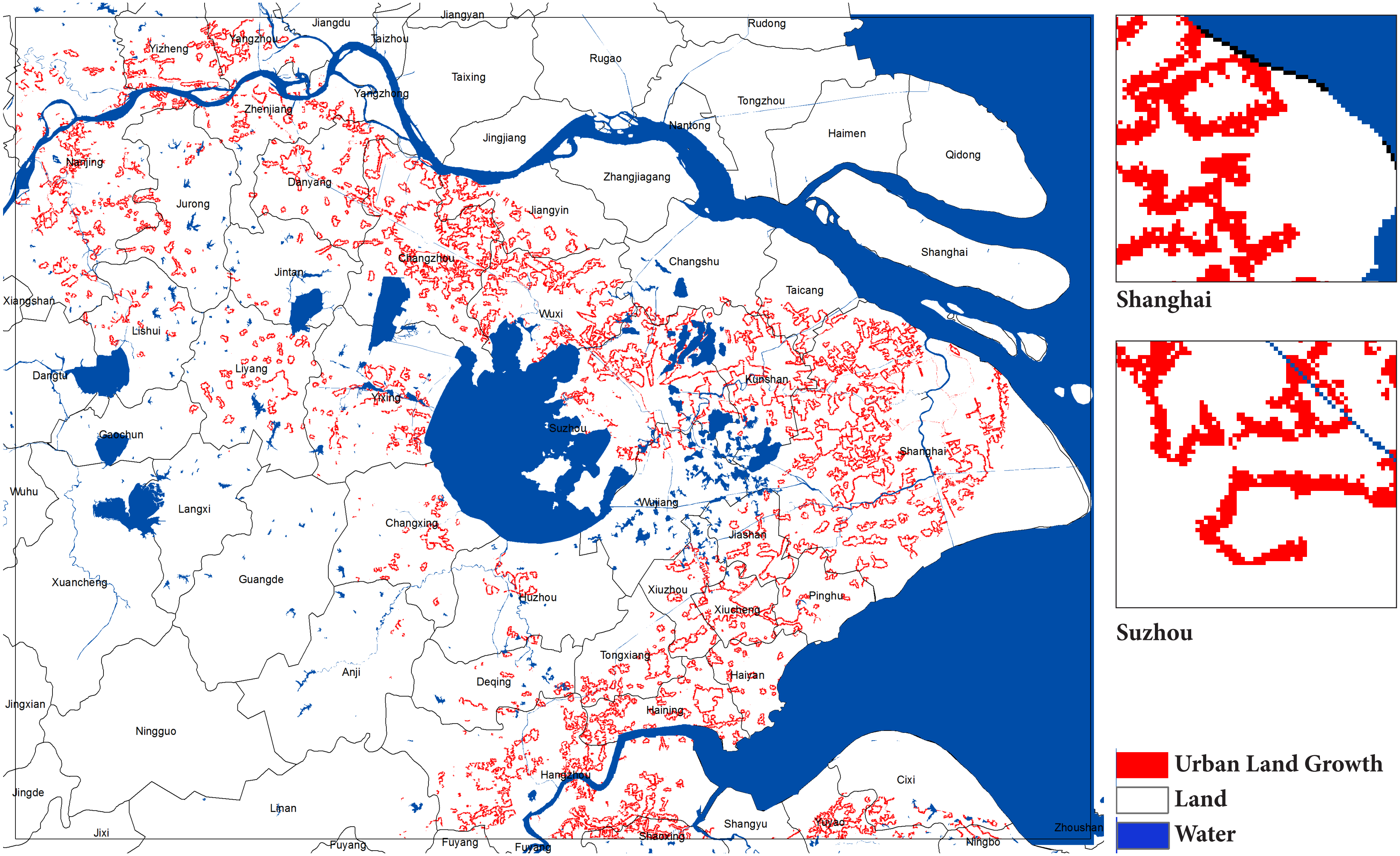
Appendix 2. Scenario 1: development corridors model prediction and analysis for the Changjiang Delta Region.
b. Interim year changes of the Scenario Cellular Automata model prediction, 2011-2020.



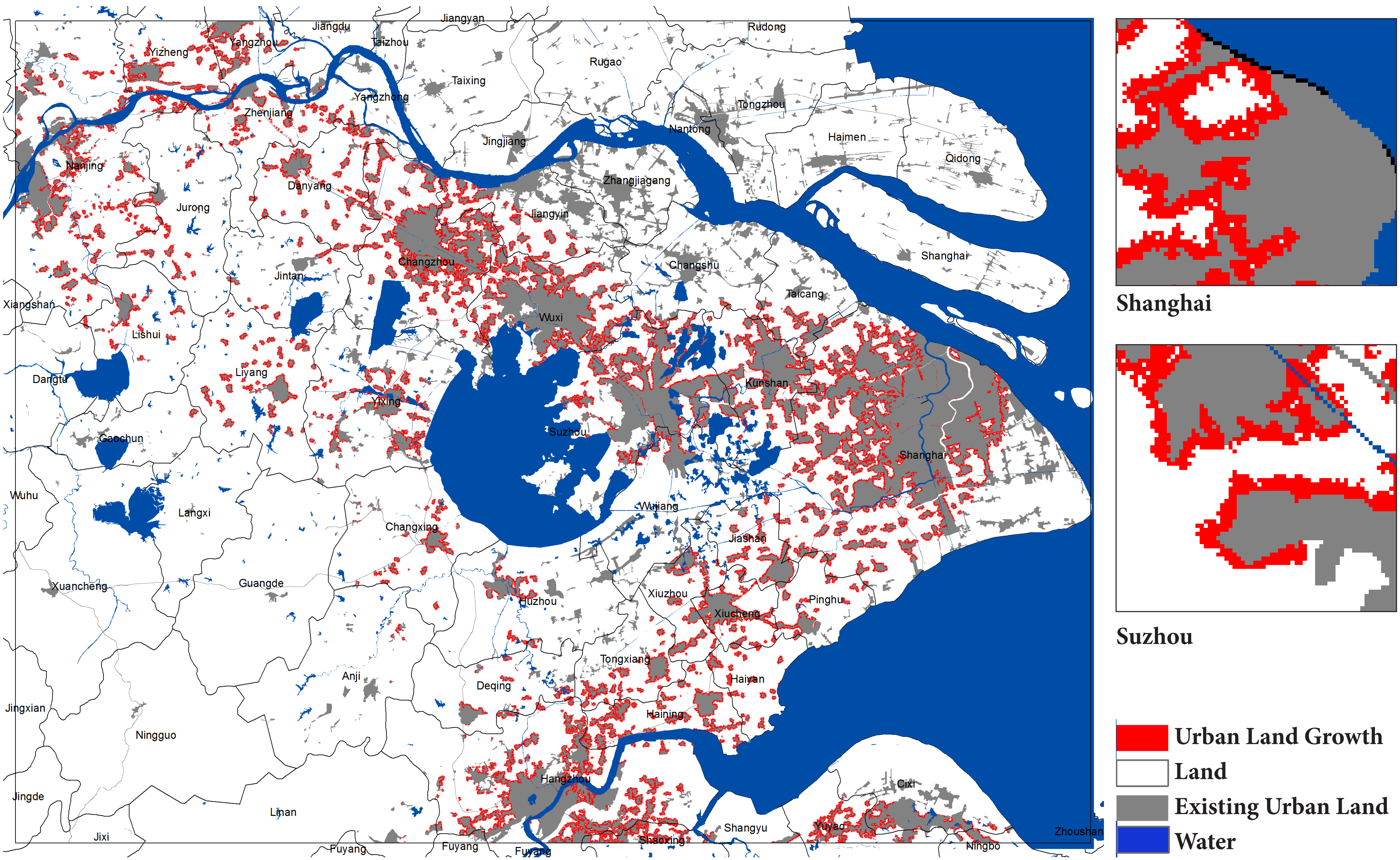
Appendix 2. Scenario 1: development corridors model prediction and analysis for the Changjiang Delta Region.
b. Interim year changes of the Scenario Cellular Automata model prediction, 2020-2030.



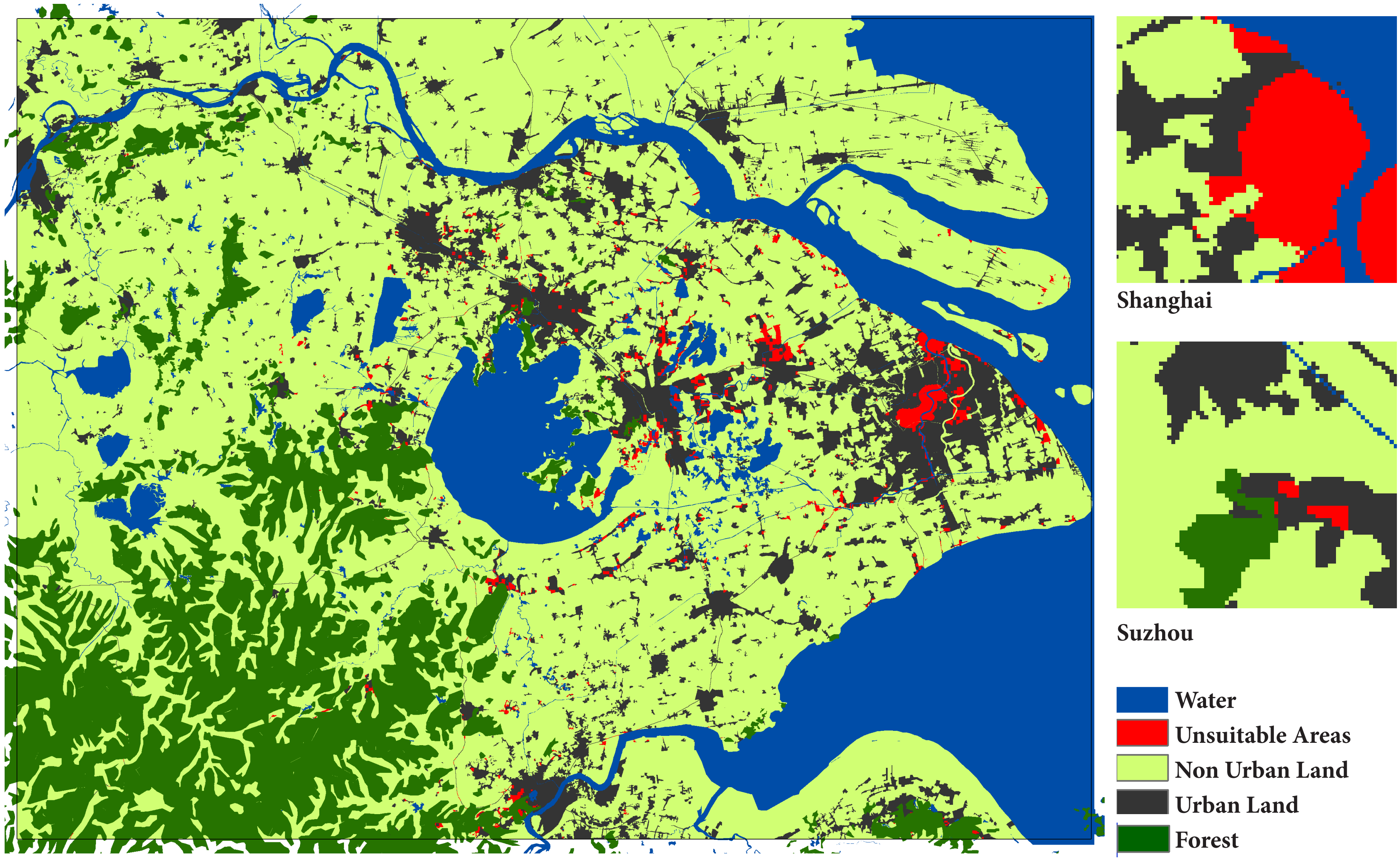
Appendix 2. Scenario 1: development corridors model prediction and analysis for the Changjiang Delta Region.
b. Interim year changes of the Scenario Cellular Automata model prediction, 2011-2030.



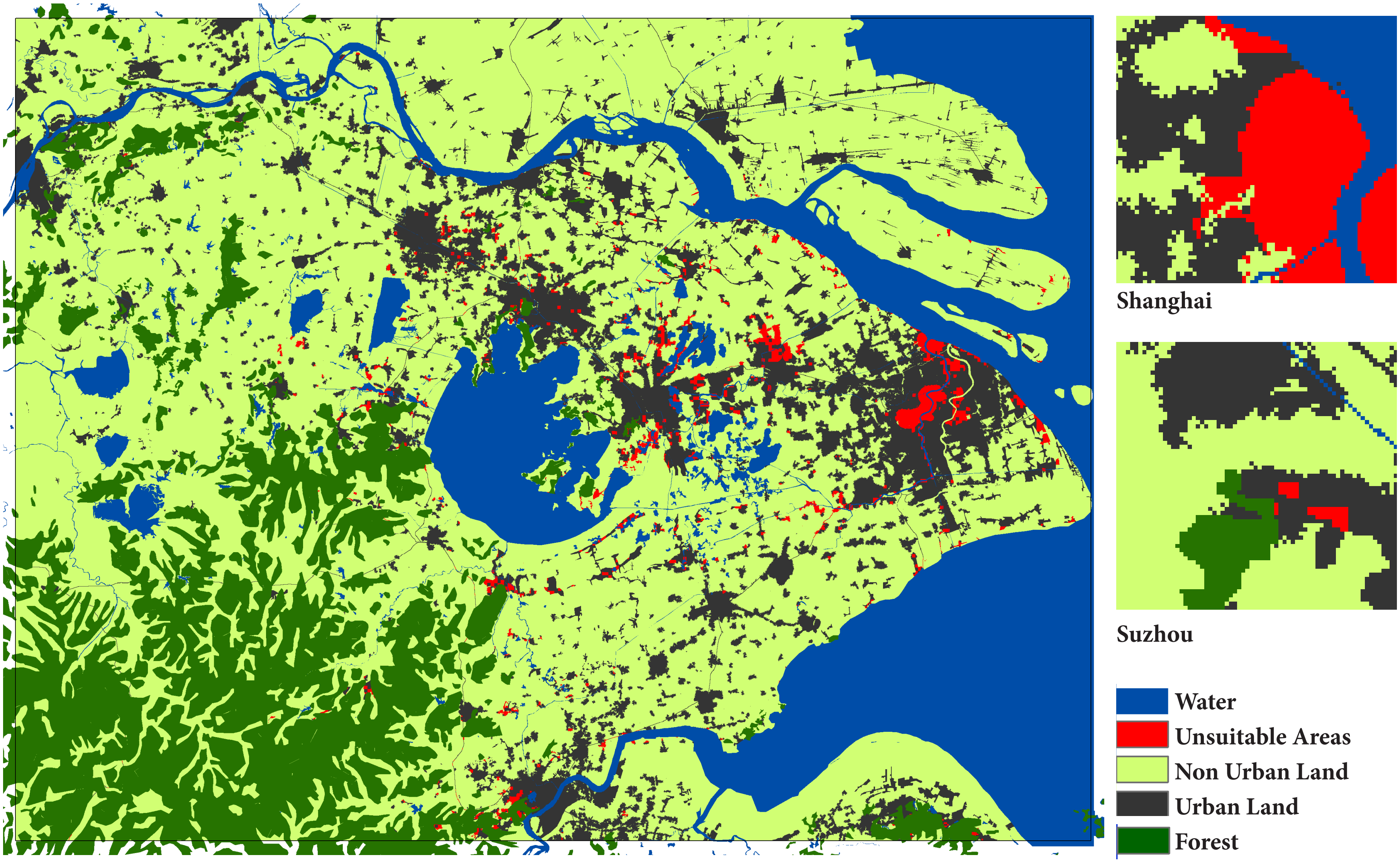
Appendix 2. Scenario 1: development corridors model prediction and analysis for the Changjiang Delta Region.
b. Interim year changes of the Scenario Cellular Automata model prediction with existing urban conditions, 2011-2030.



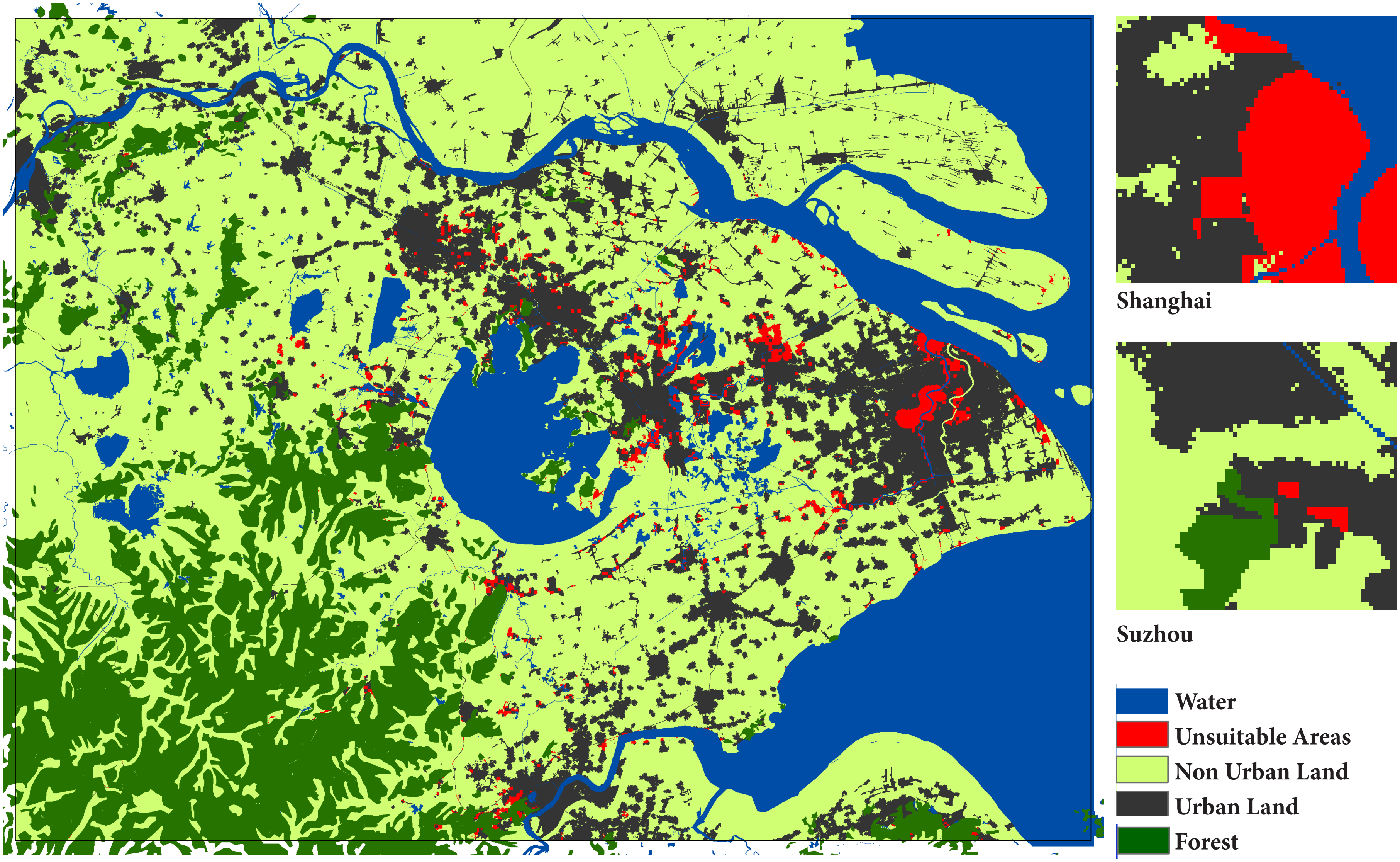
Appendix 2. Scenario 1: development corridors model prediction and analysis for the Changjiang Delta Region.
c. Unsuitable urban growth area, baseline1: envrionmental suitability vs. scenario 1: development corridors, 2011.



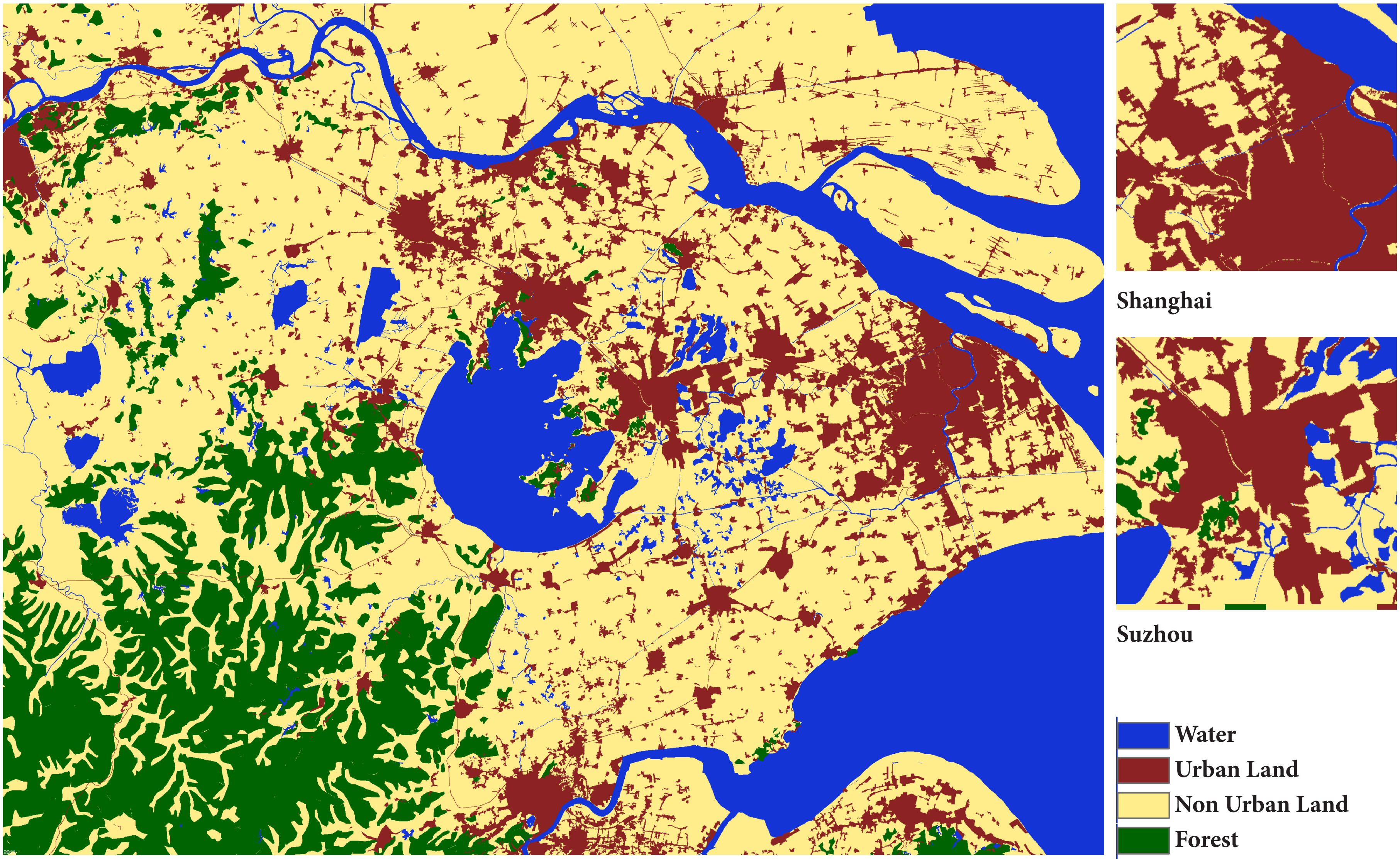
Appendix 2. Scenario 1: development corridors model prediction and analysis for the Changjiang Delta Region.
c. Unsuitable urban growth area, baseline1: envrionmental suitability vs. scenario 1: development corridors, 2020.



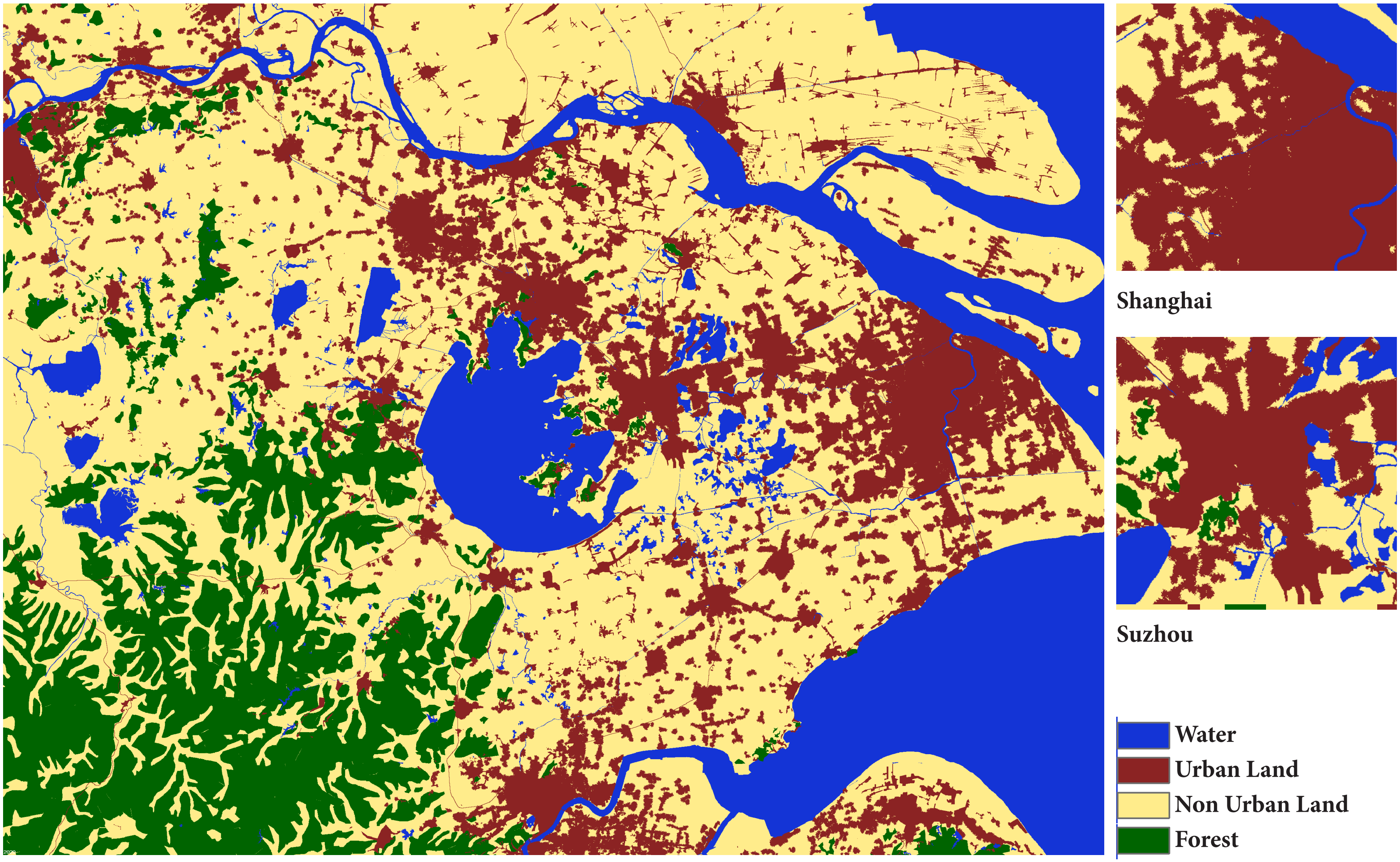
Appendix 2. Scenario 1: development corridors model prediction and analysis for the Changjiang Delta Region.
c. Unsuitable urban growth area, baseline1: envrionmental suitability vs. scenario 1: development corridors, 2030.



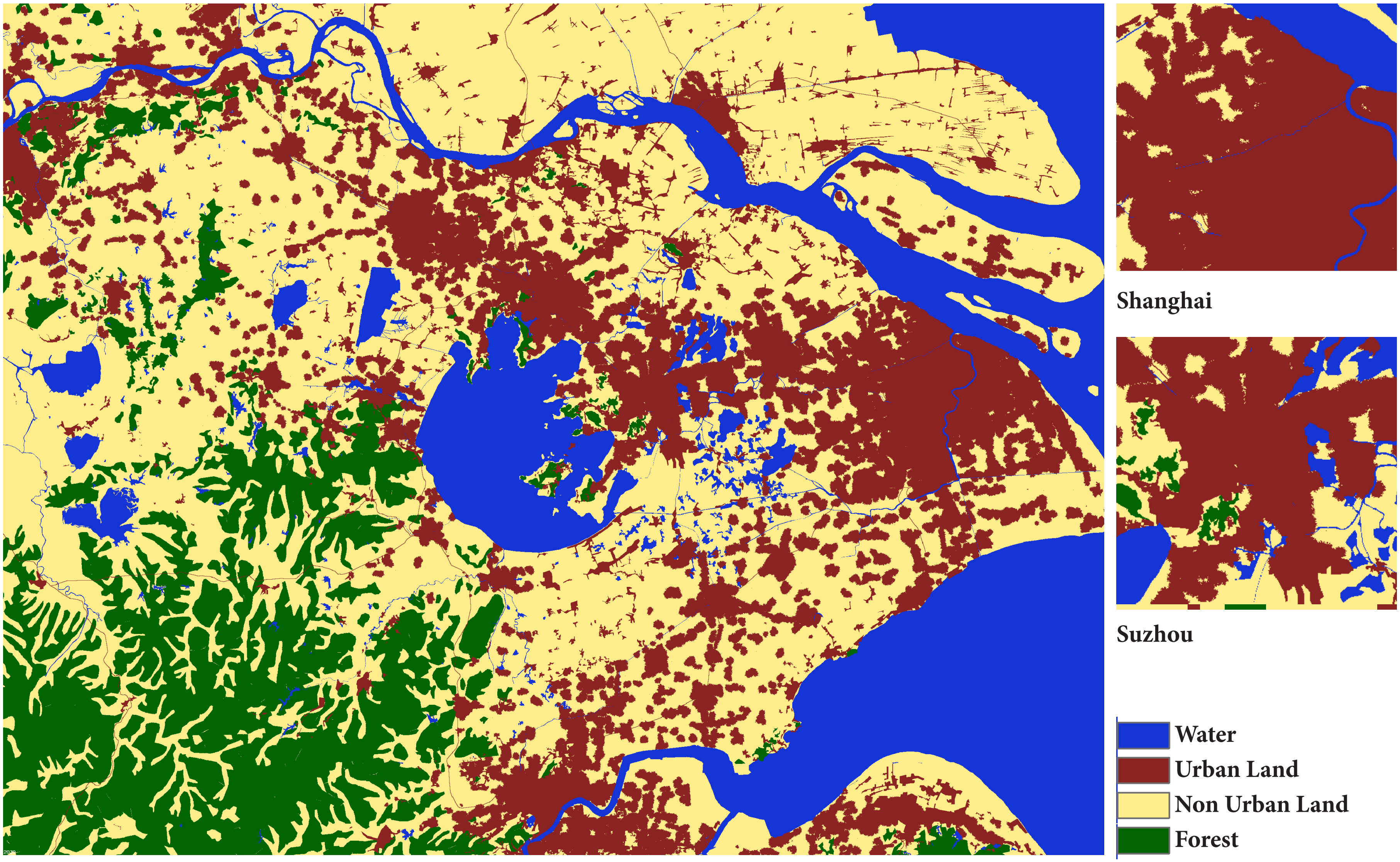
Appendix 3. Scenario 2: development corridors, plus big city growth model prediction and analysis for the Changjiang Delta Region.
a. Scenario Cellular Automata model prediction, 2011.



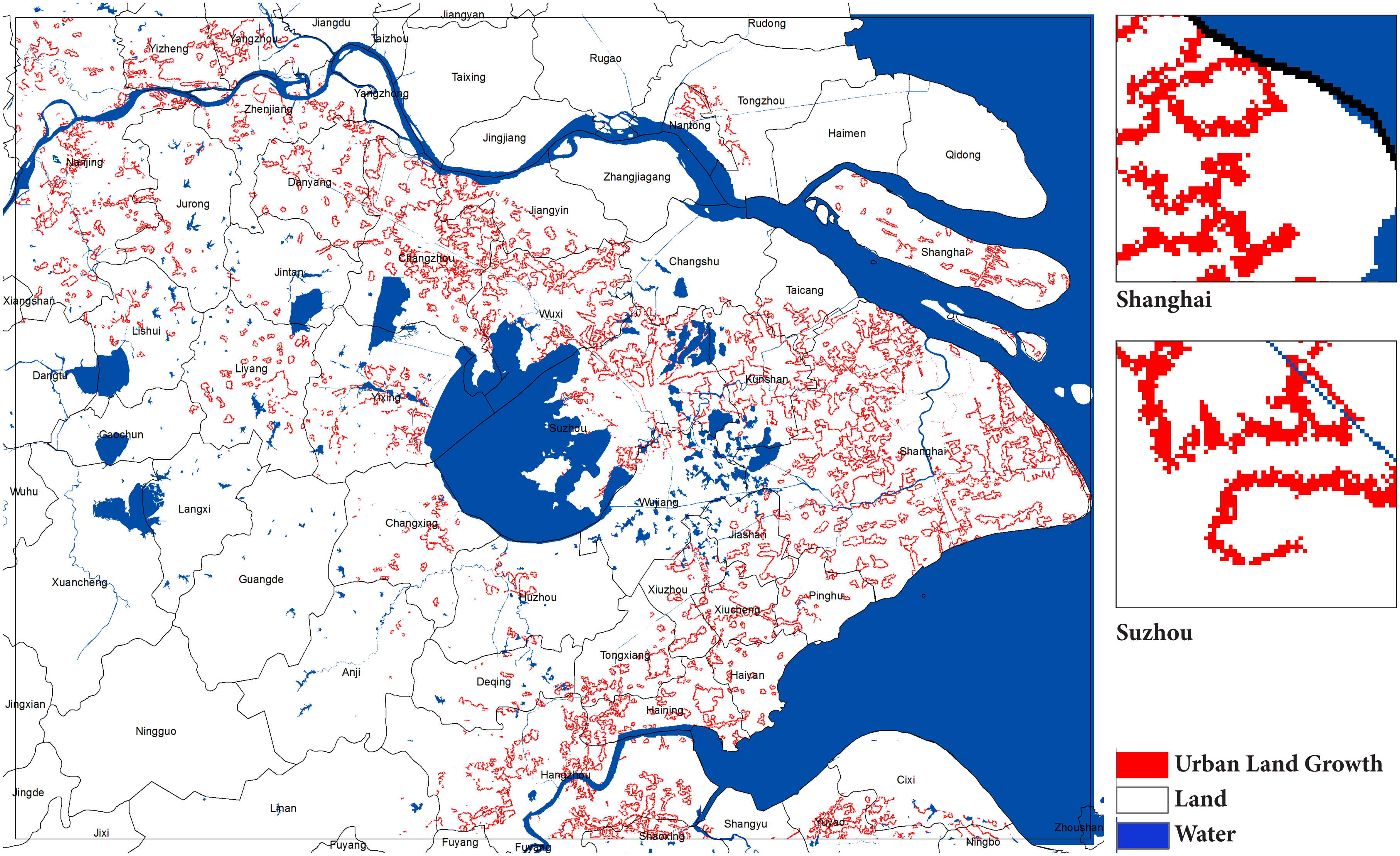
Appendix 3. Scenario 2: development corridors, plus big city growth model prediction and analysis for the Changjiang Delta Region.
a. Scenario Cellular Automata model prediction, 2020.



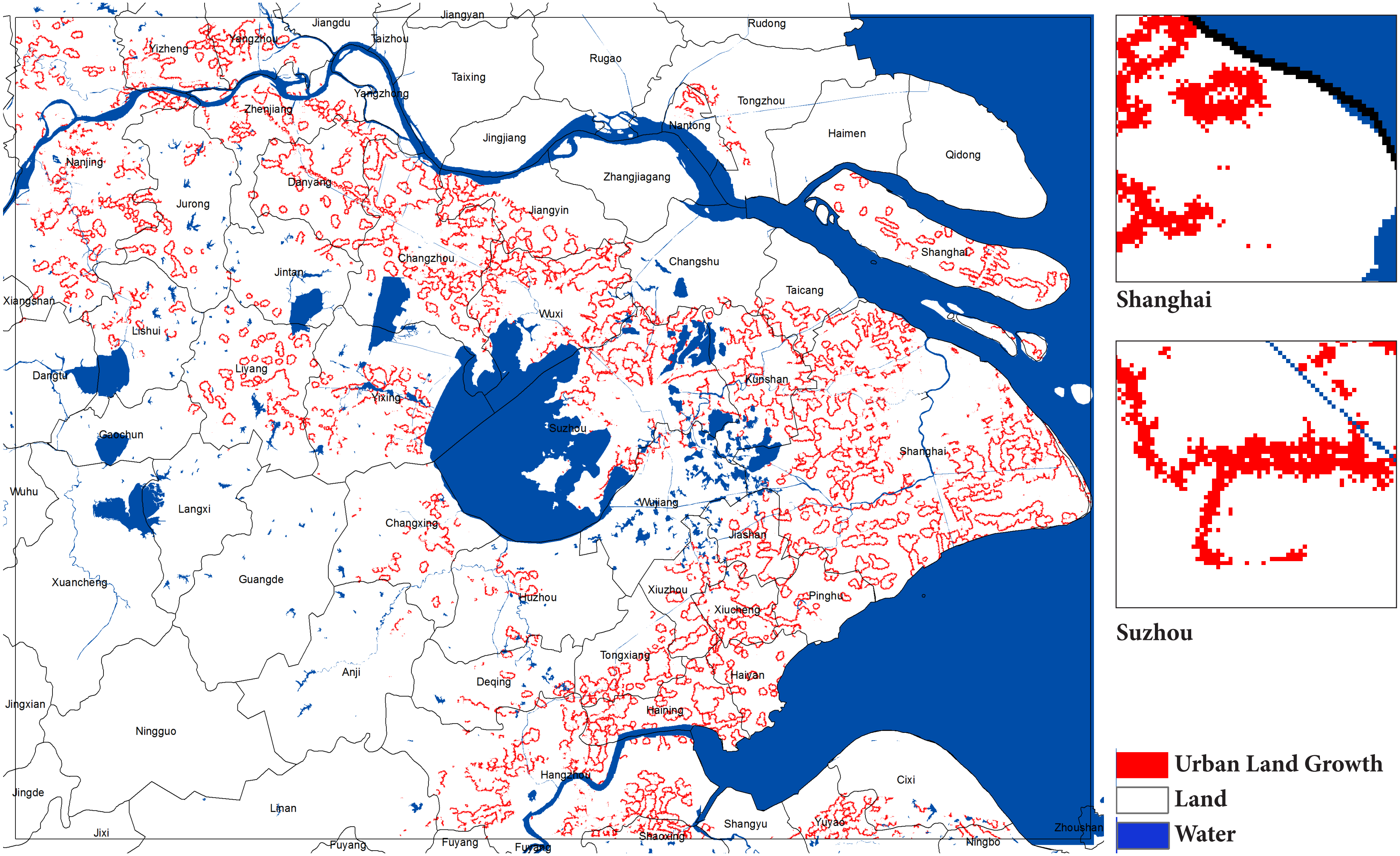
Appendix 3. Scenario 2: development corridors, plus big city growth model prediction and analysis for the Changjiang Delta Region.
a. Scenario Cellular Automata model prediction, 2030.



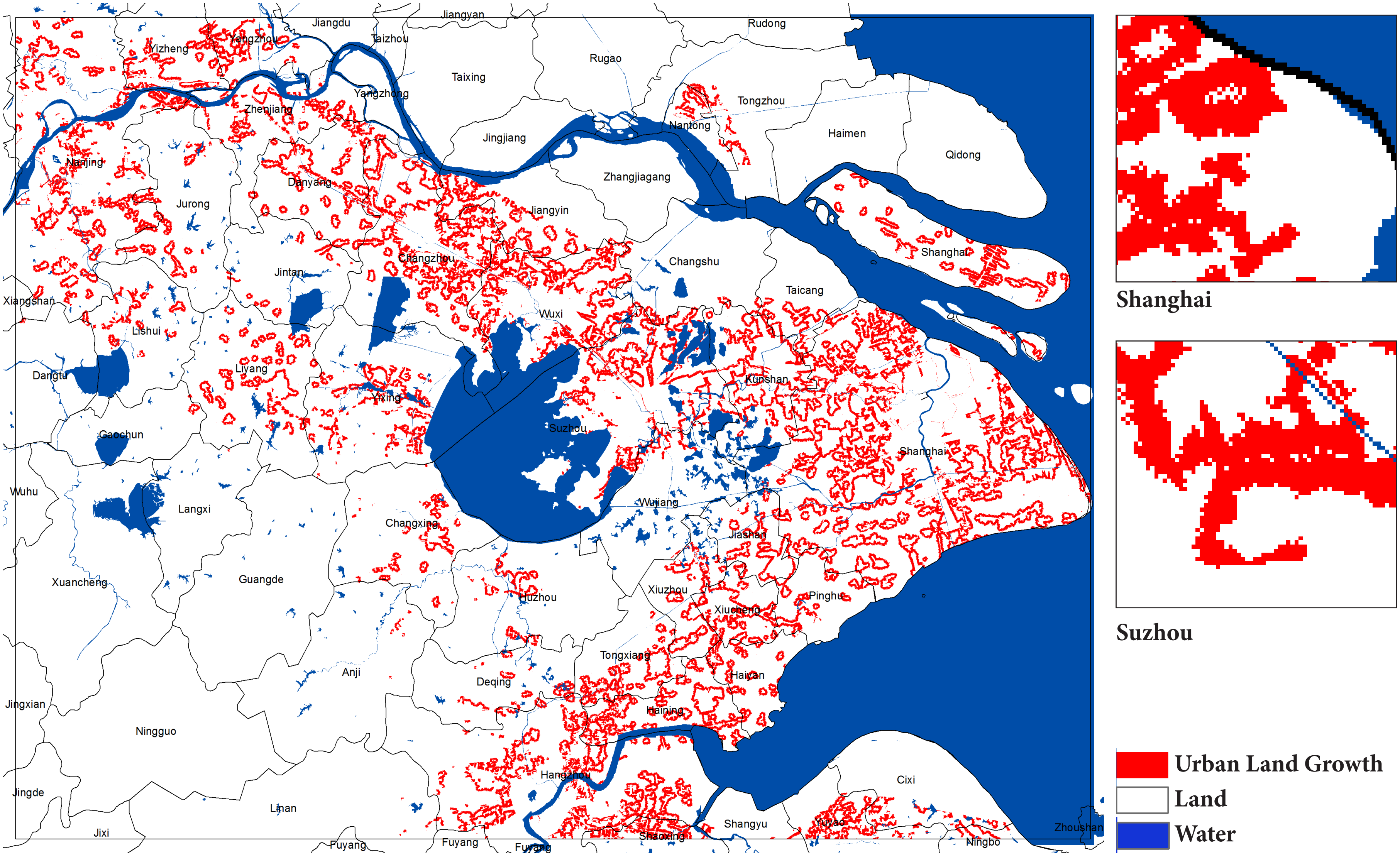
Appendix 3. Scenario 2: development corridors, plus big city growth model prediction and analysis for the Changjiang Delta Region.
b. Interim year changes of the Scenario Cellular Automata model prediction, 2011-2020.



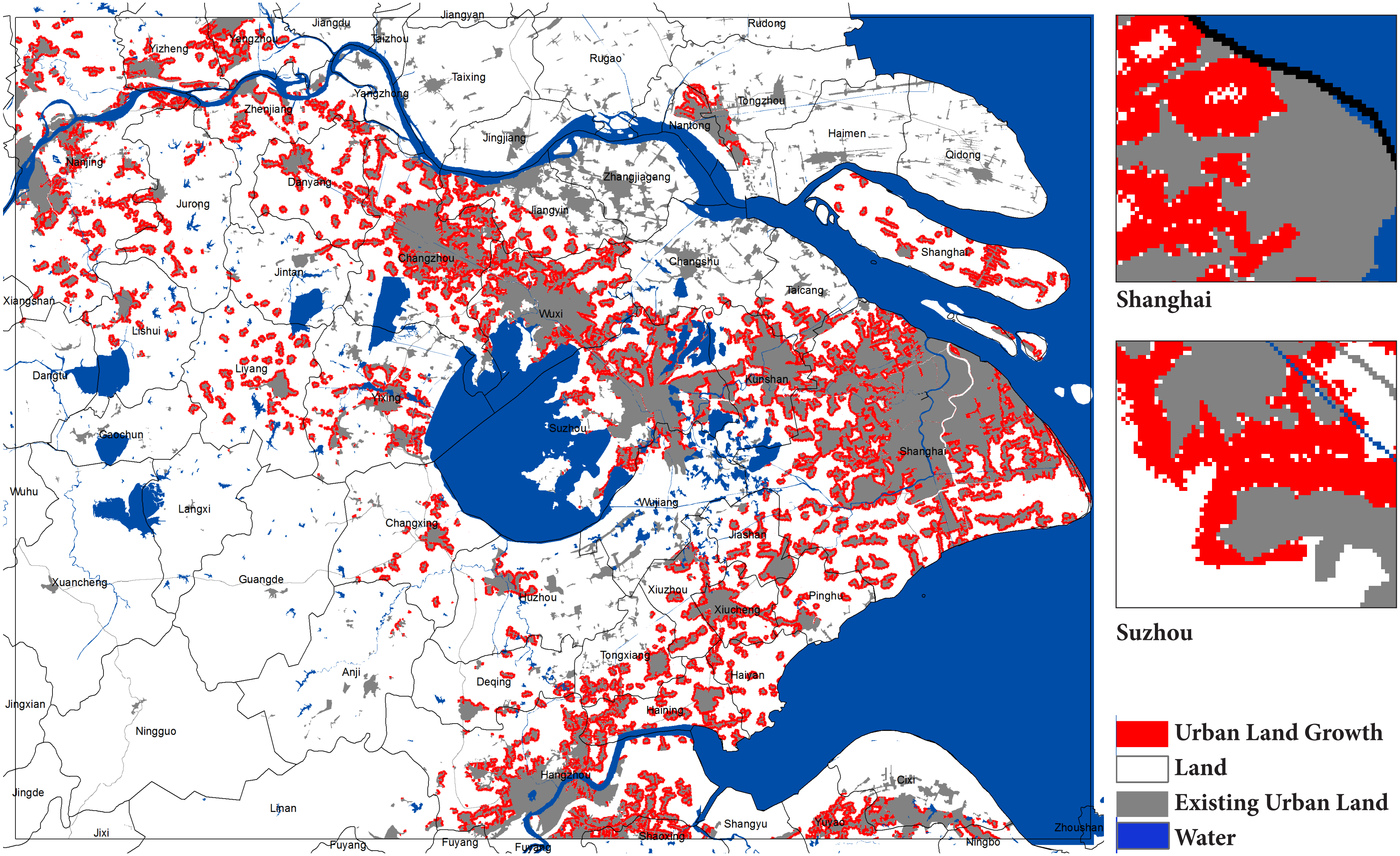
Appendix 3. Scenario 2: development corridors, plus big city growth model prediction and analysis for the Changjiang Delta Region. b. Interim year changes of the Scenario Cellular Automata model prediction, 2020-2030.



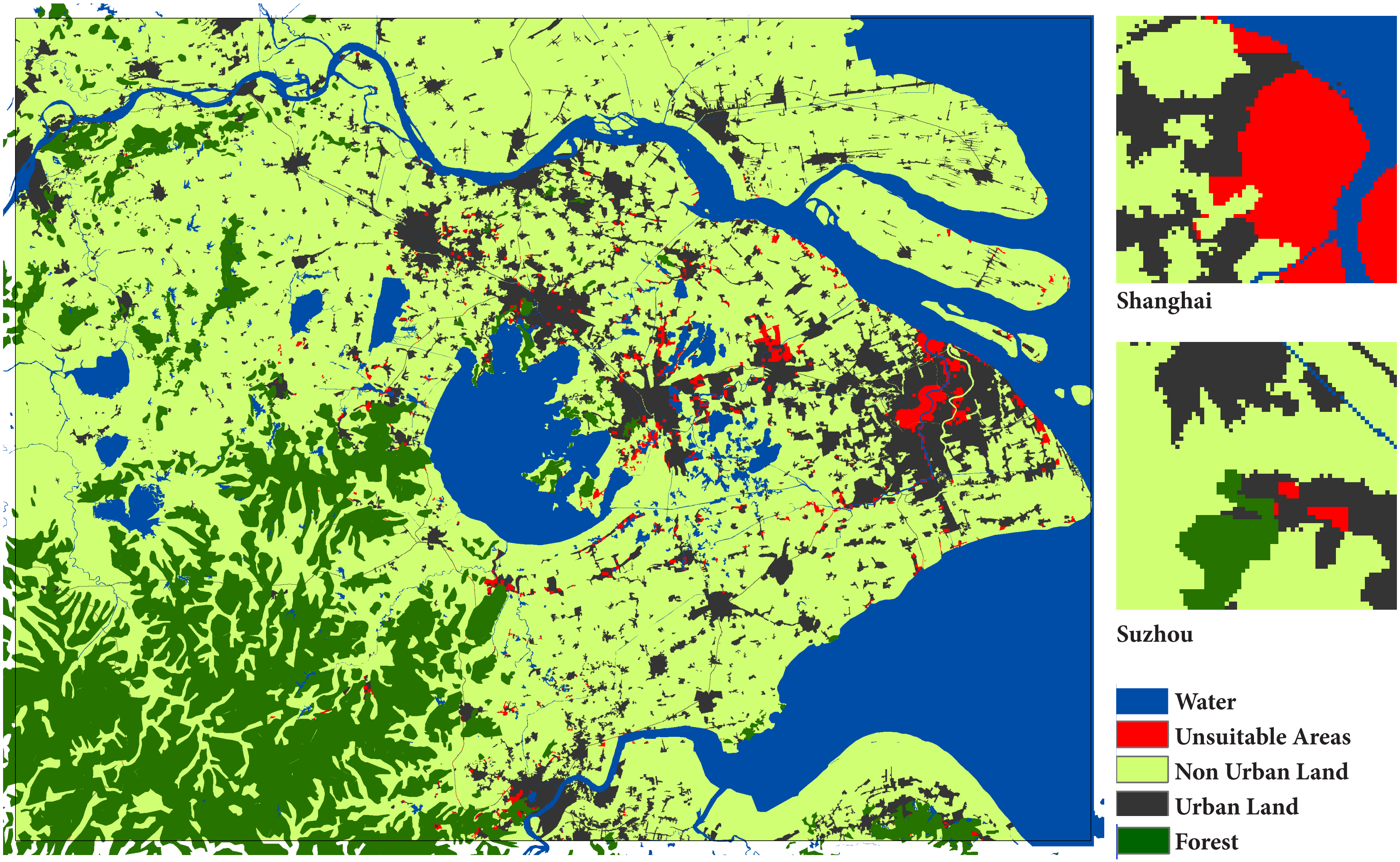
Appendix 3. Scenario 2: development corridors, plus big city growth model prediction and analysis for the Changjiang Delta Region.
b. Interim year changes of the Scenario Cellular Automata model prediction, 2011-2030.



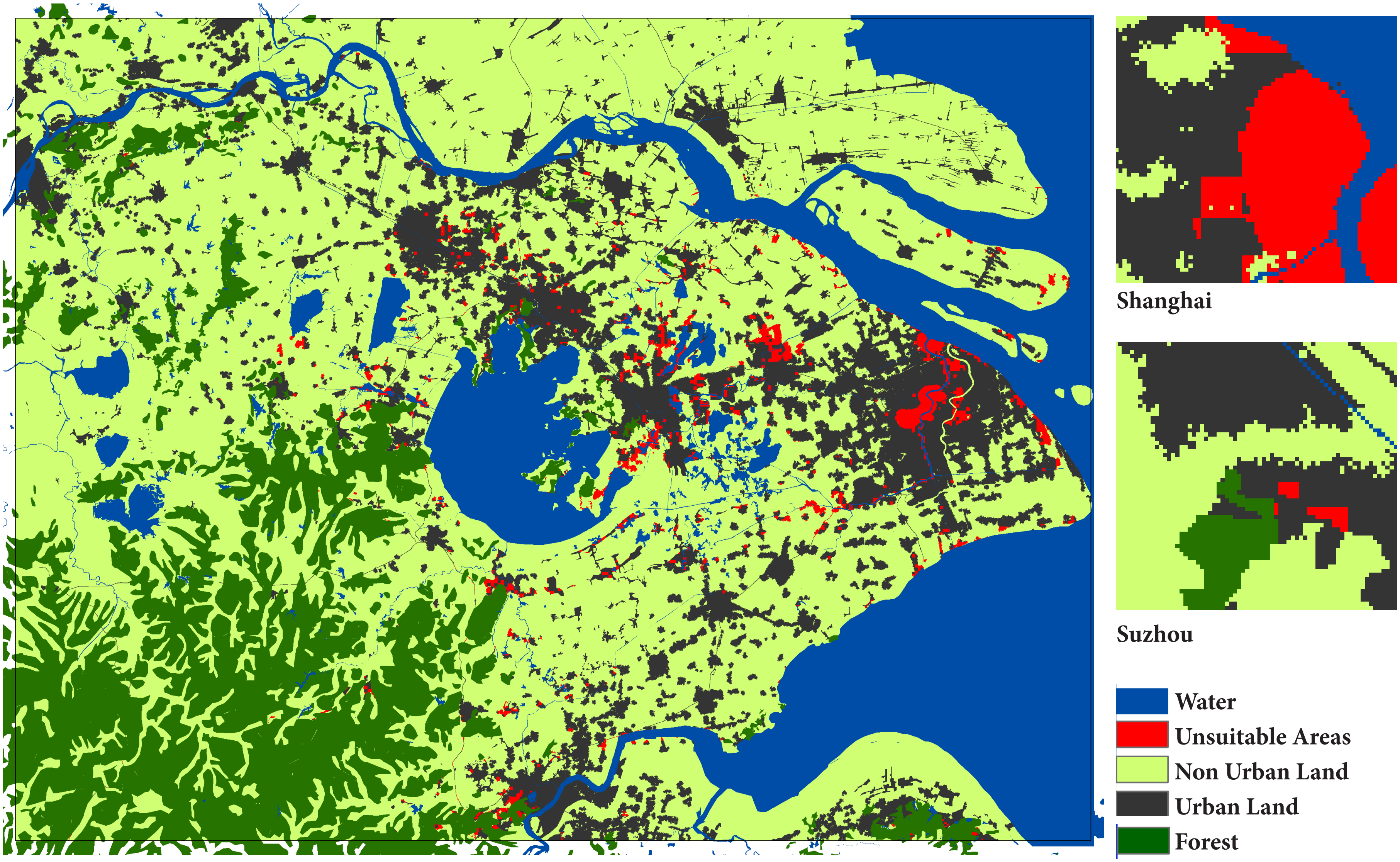
Appendix 3. Scenario 2: development corridors, plus big city growth model prediction and analysis for the Changjiang Delta Region.
b. Interim year changes of the Scenario Cellular Automata model prediction with existing urban conditions, 2011-2030.



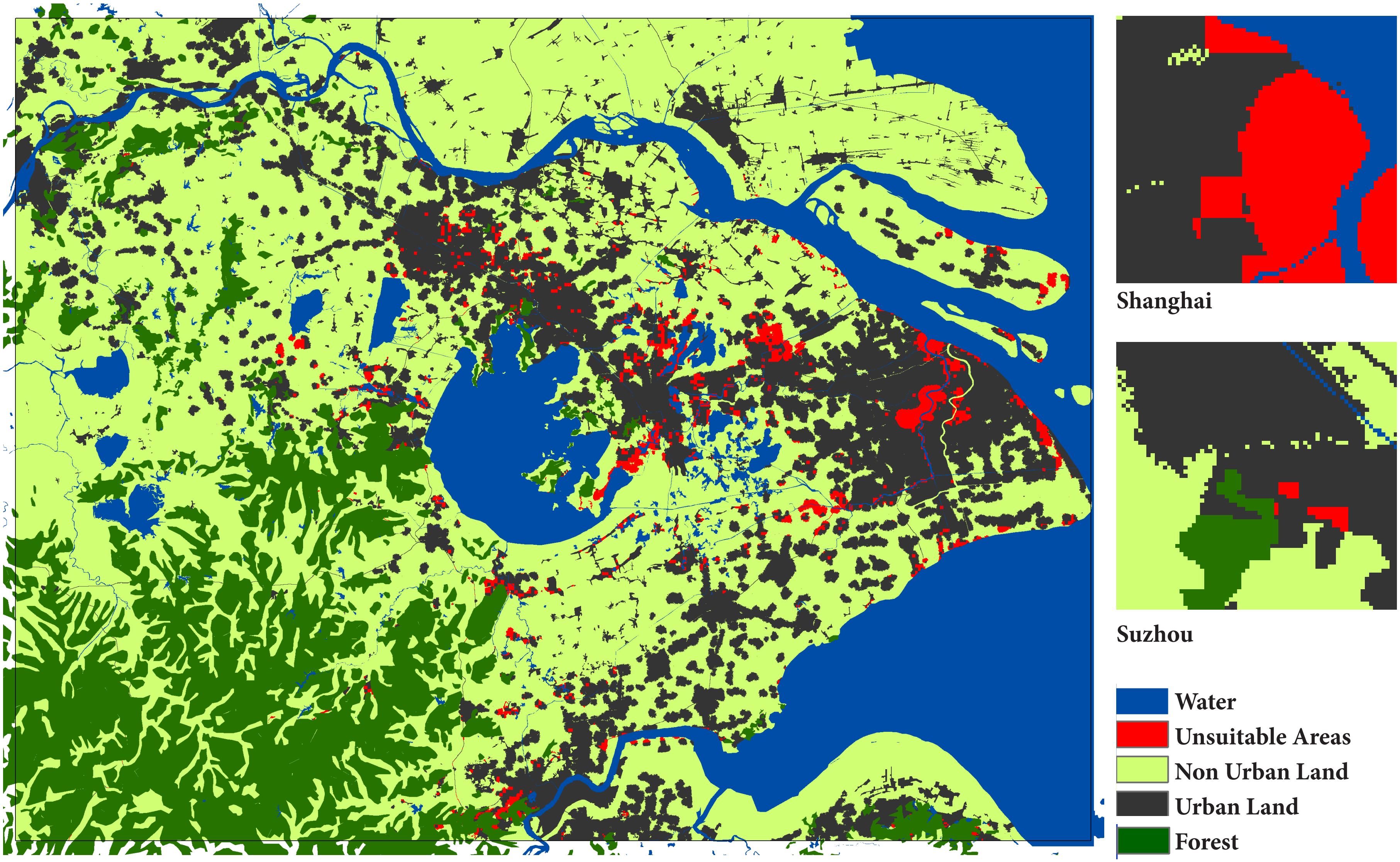
Appendix 3. Scenario 2: development corridors, plus big city growth model prediction and analysis for the Changjiang Delta Region.
c. Unsuitable urban growth area, baseline1: envrionmental suitability vs. scenario 2: development corridors, plus big city growth 2011.



Appendix 3. Scenario 2: development corridors, plus big city growth model prediction and analysis for the Changjiang Delta Region.
c. Unsuitable urban growth area, baseline1: envrionmental suitability vs. scenario 2: development corridors, plus big city growth 2020.

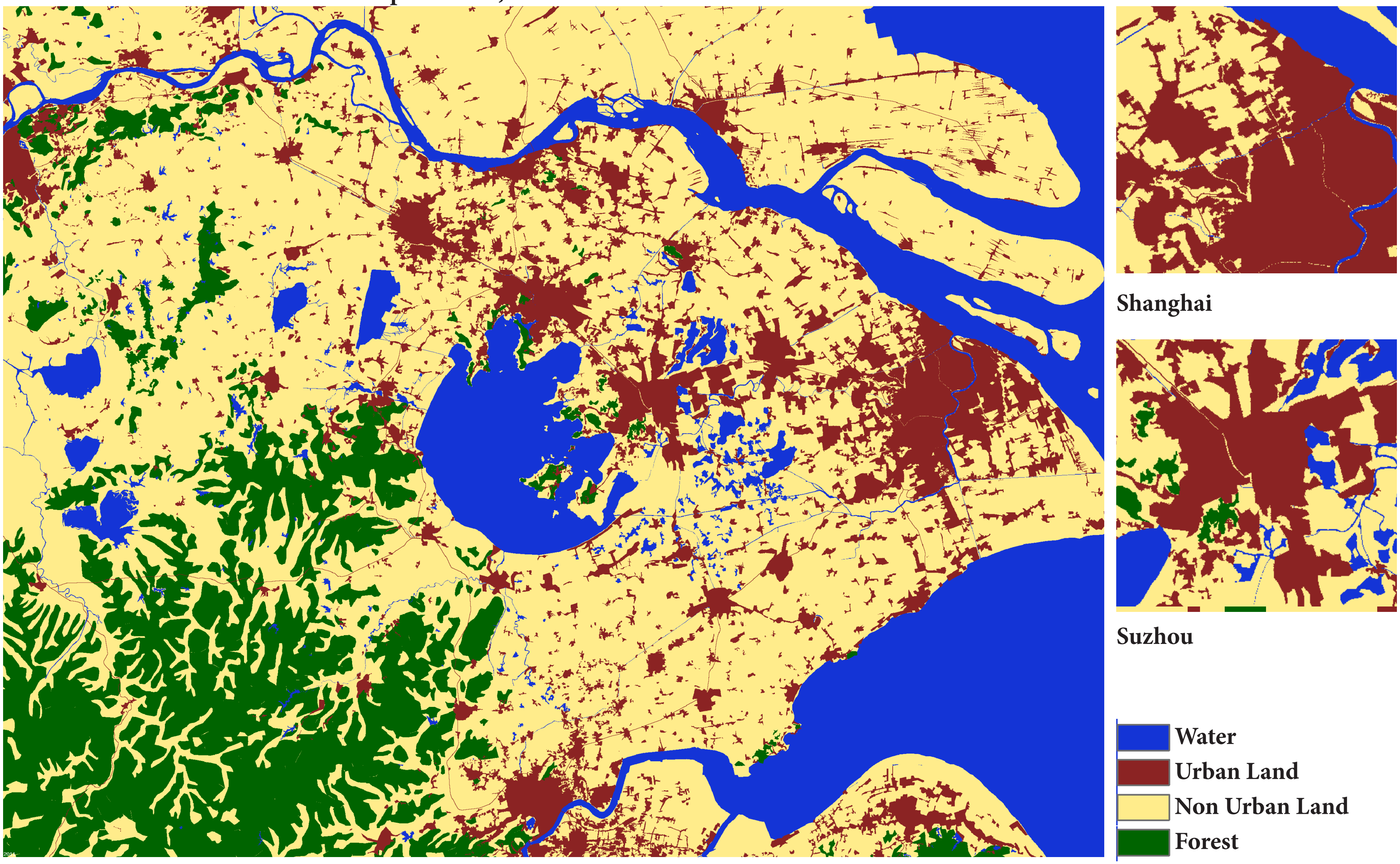


Appendix 3. Scenario 2: development corridors, plus big city growth model prediction and analysis for the Changjiang Delta Region.
c. Unsuitable urban growth area, baseline1: envrionmental suitability vs. scenario 2: development corridors, plus big city growth 2030.



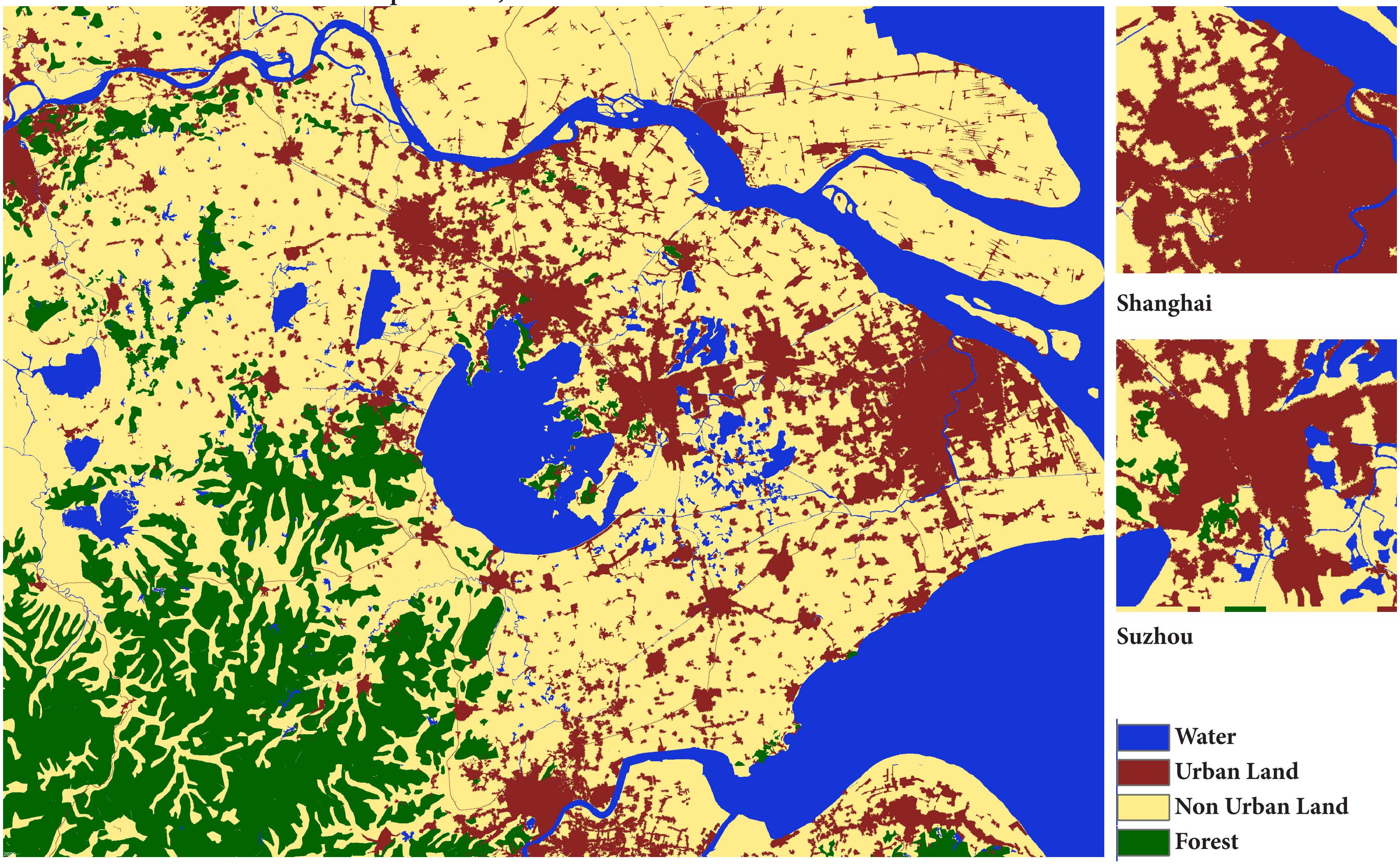
Appendix 4. Scenario 3: ecological system concern (forest protection), plus development corridors, urban growth model prediction and analysis for the Changjiang Delta Region.

a. Scenario Cellular Automata model prediction, 2011.

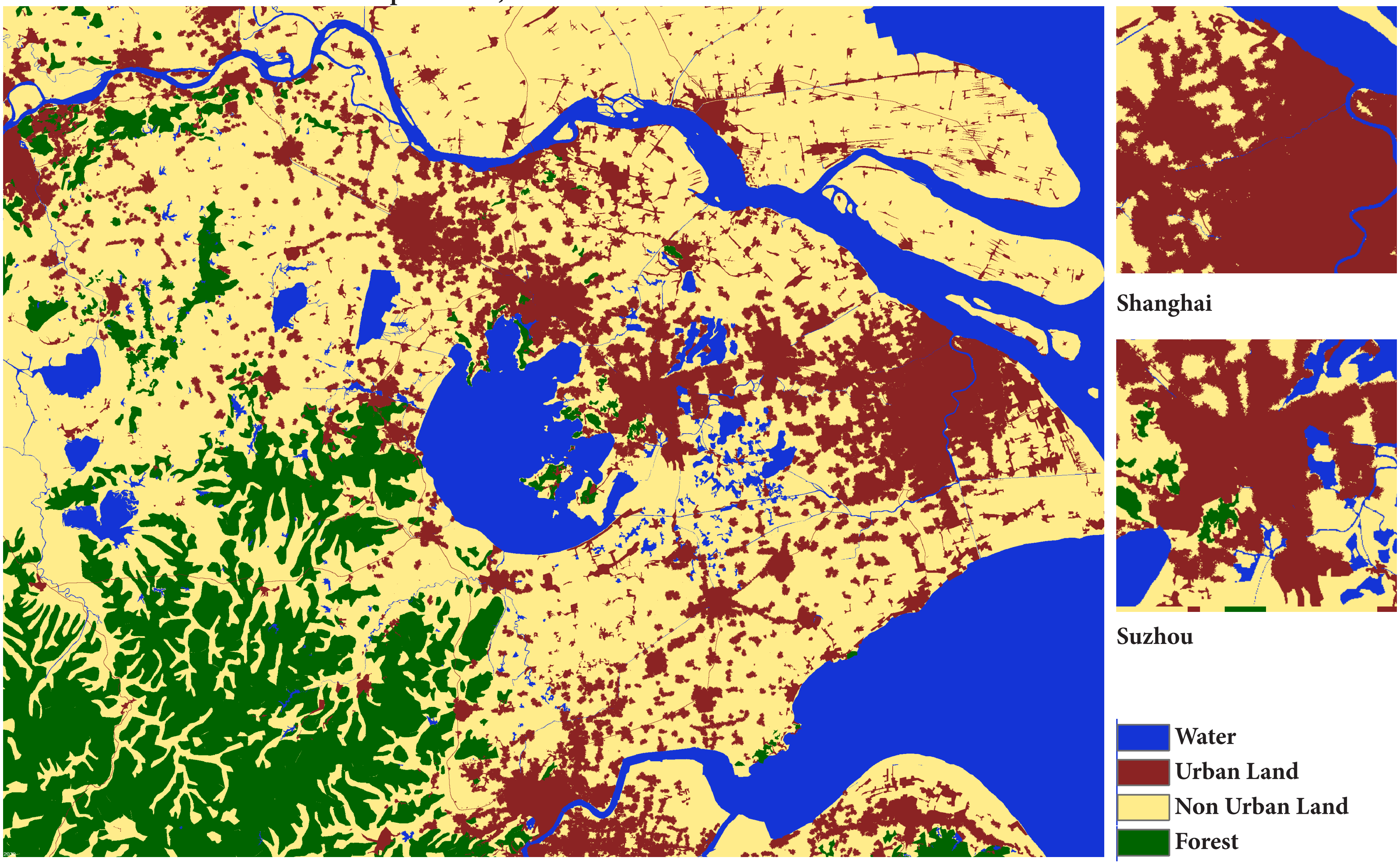


Appendix 4. Scenario 3: ecological system concern (forest protection), plus development corridors, urban growth model prediction and analysis for the Changjiang Delta Region.

a. Scenario Cellular Automata model prediction, 2020.

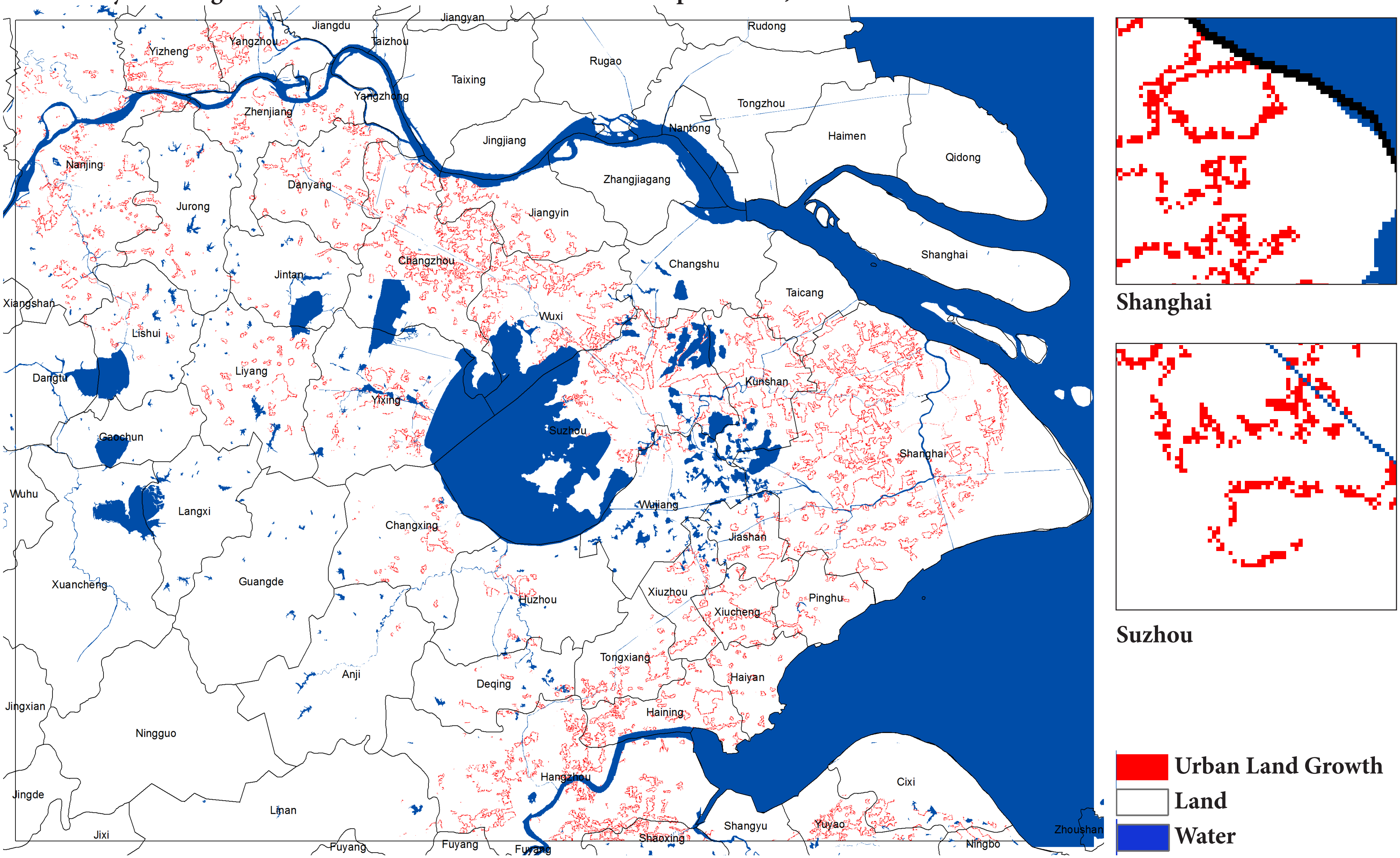


Appendix 4. Scenario 3: ecological system concern (forest protection), plus development corridors, urban growth model prediction and analysis for the Changjiang Delta Region.
a. Scenario Cellular Automata model prediction, 2030.



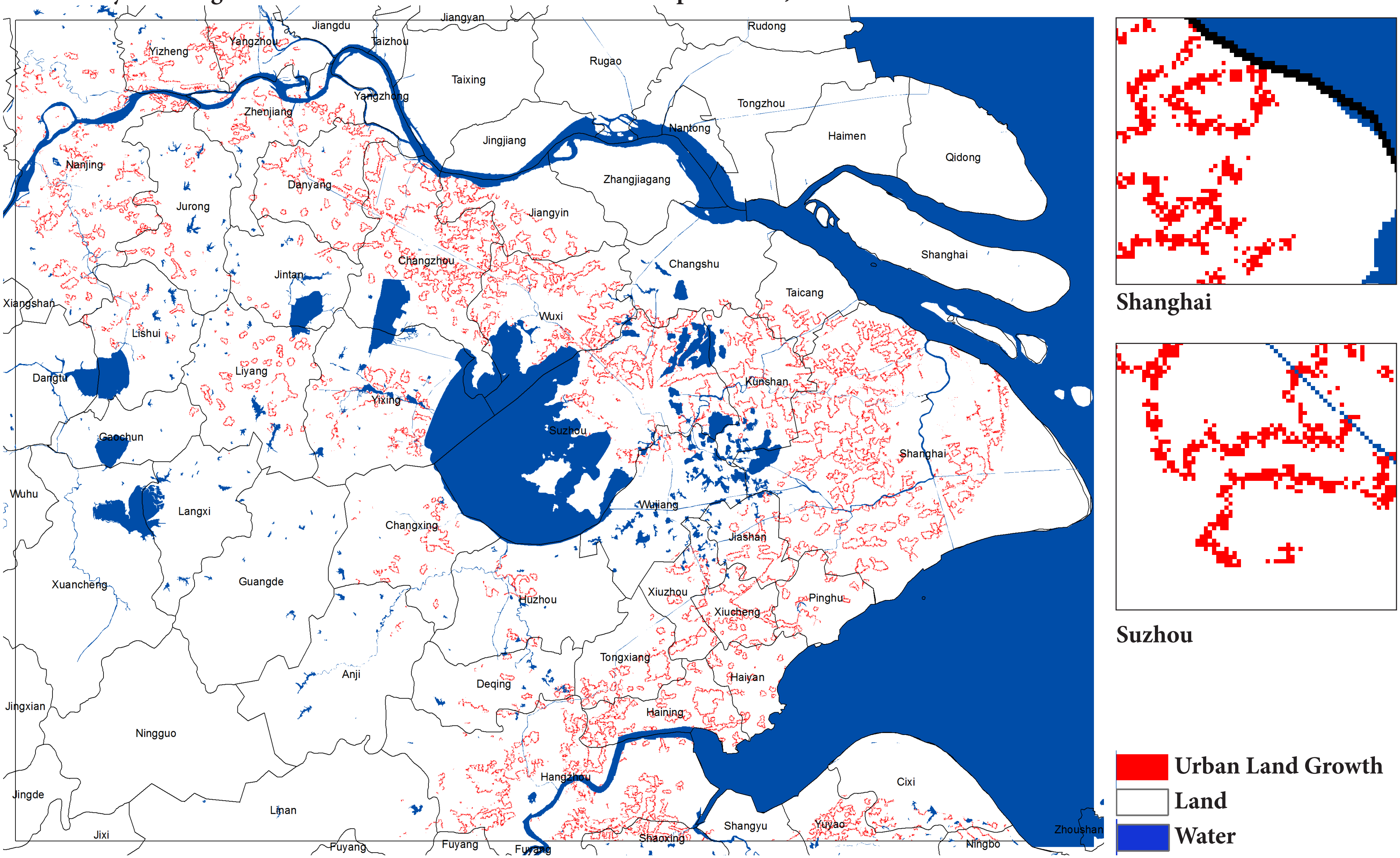
Appendix 4. Scenario 3: ecological system concern (forest protection), plus development corridors, urban growth model prediction and analysis for the Changjiang Delta Region.

b. Interim year changes of the Scenario Cellular Automata model prediction, 2011-2020.



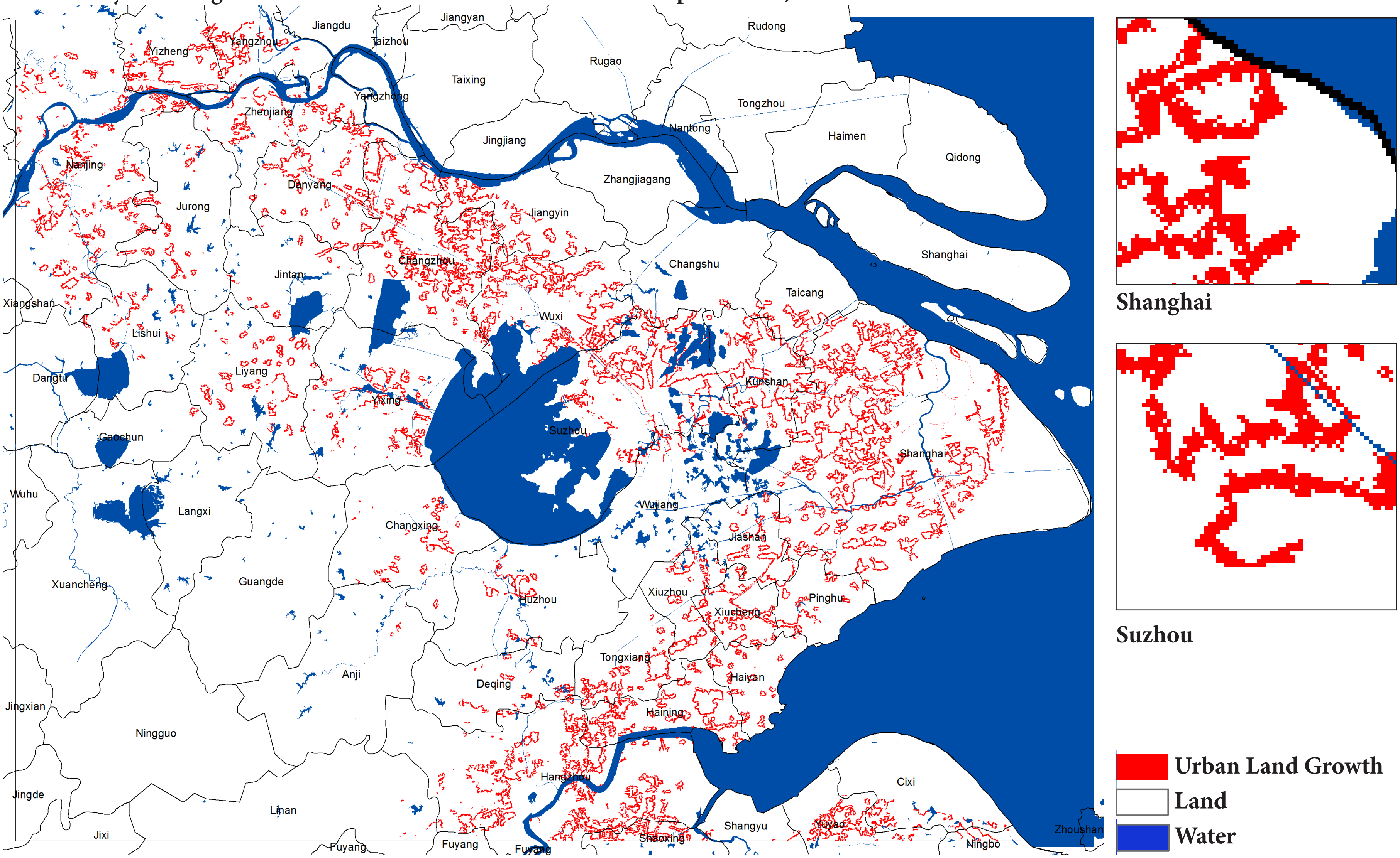
Appendix 4. Scenario 3: ecological system concern (forest protection), plus development corridors, urban growth model prediction and analysis for the Changjiang Delta Region.

b. Interim year changes of the Scenario Cellular Automata model prediction, 2020-2030.



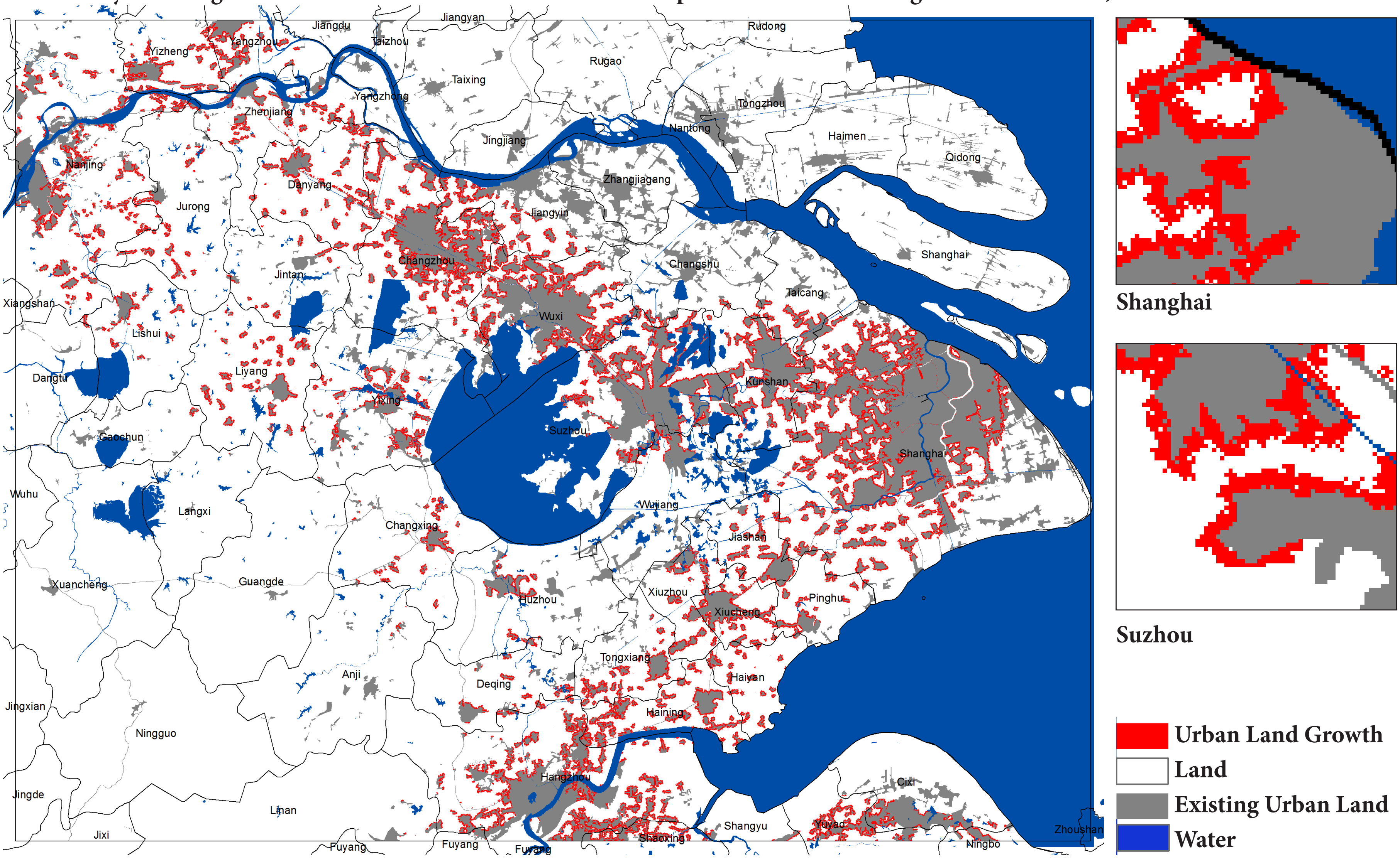
Appendix 4. Scenario 3: ecological system concern (forest protection), plus development corridors, urban growth model prediction and analysis for the Changjiang Delta Region.

b. Interim year changes of the Scenario Cellular Automata model prediction, 2011-2030.

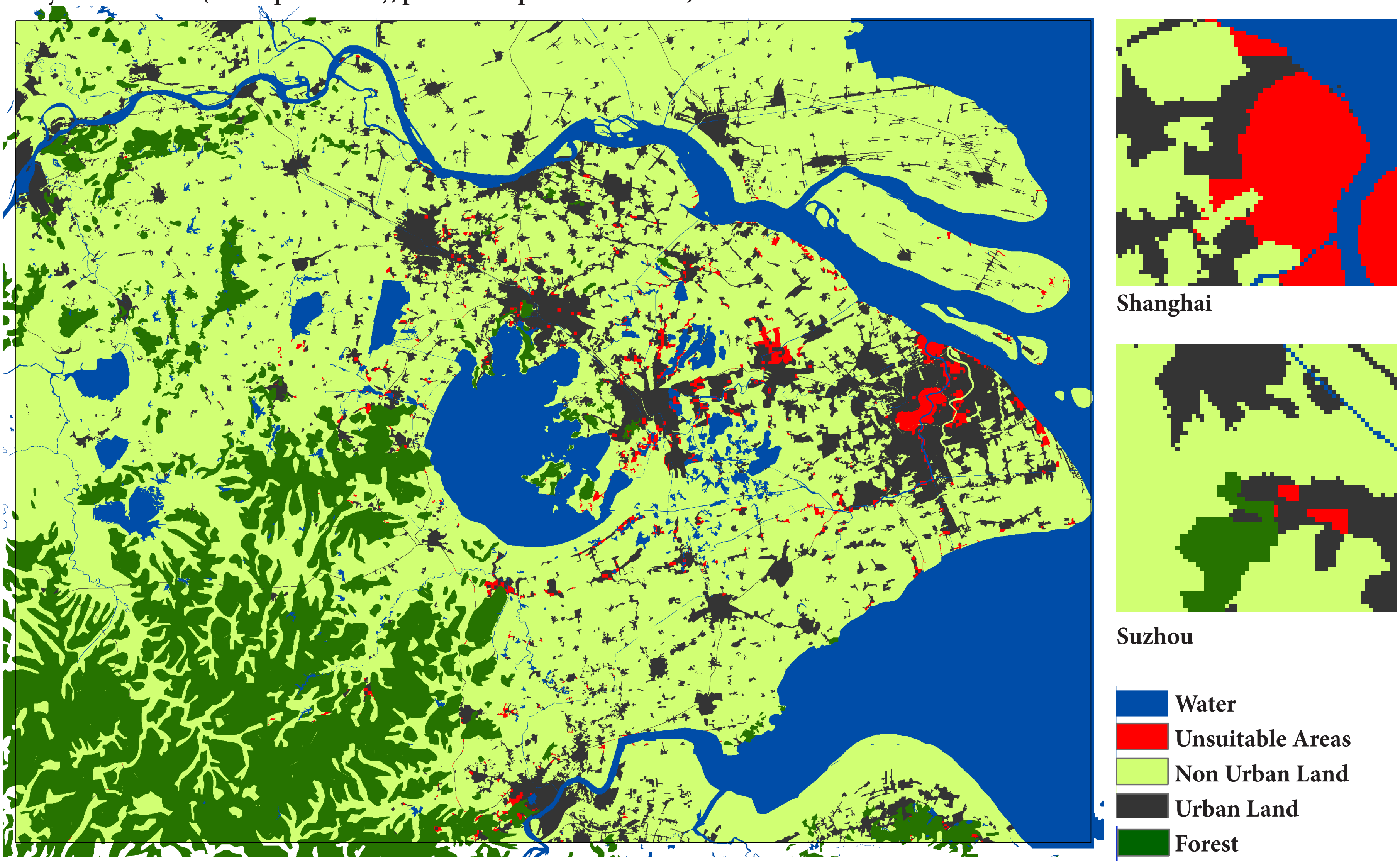


Appendix 4. Scenario 3: ecological system concern (forest protection), plus development corridors, urban growth model prediction and analysis for the Changjiang Delta Region.

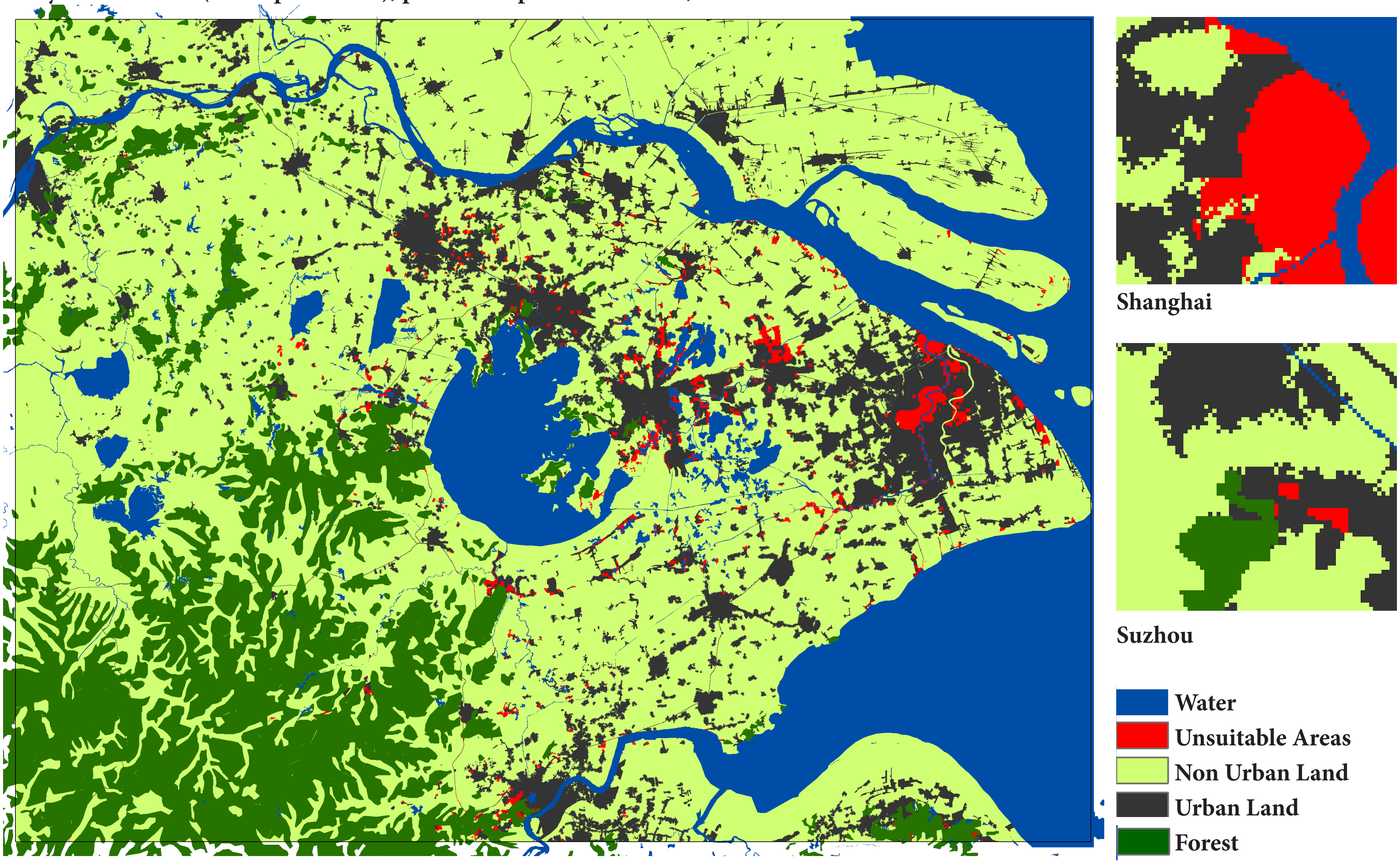
b. Interim year changes of the Scenario Cellular Automata model prediction with existing urban conditions, 2011-2030.



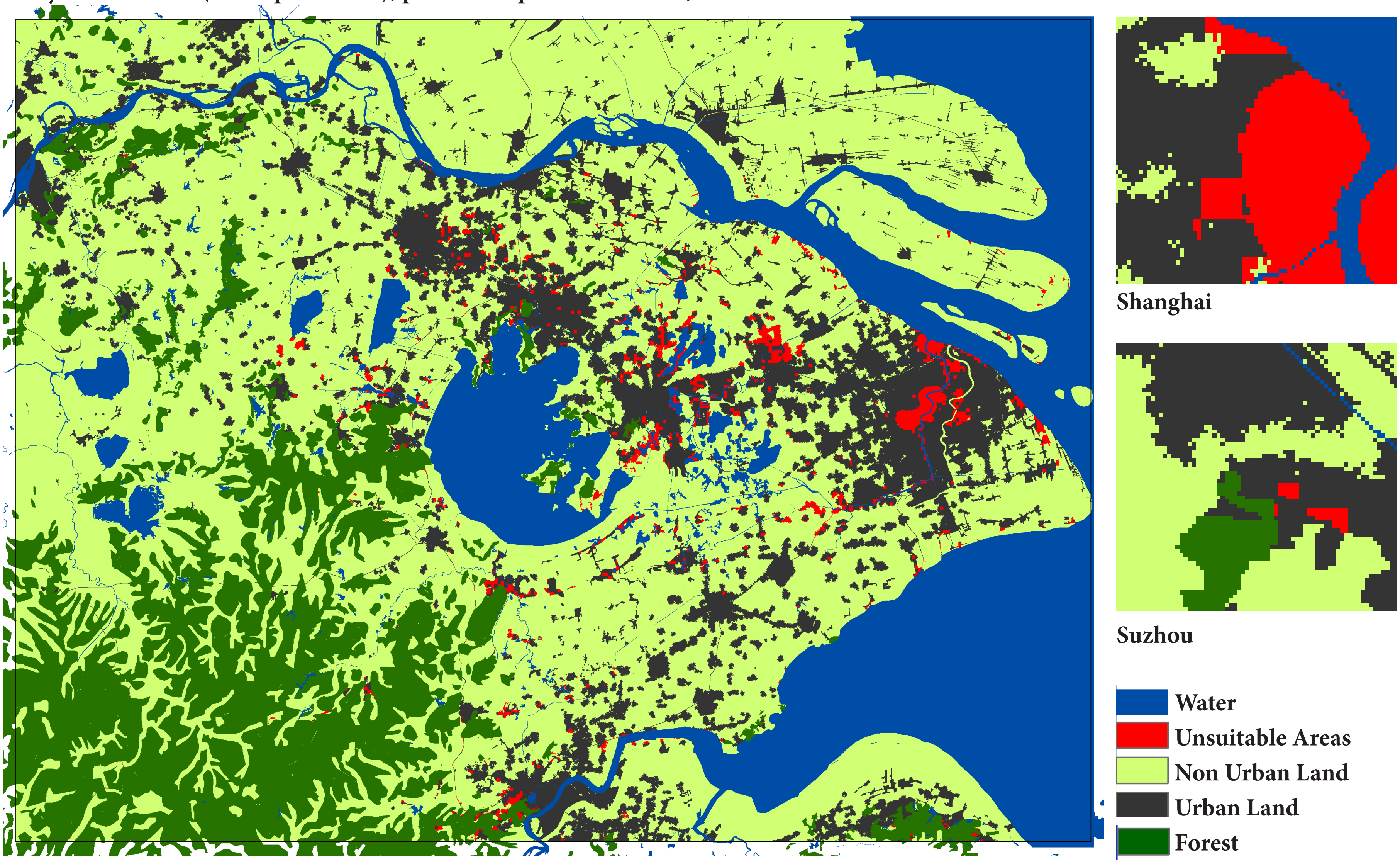
Appendix 4. Scenario 3: ecological system concern (forest protection), plus development corridors, urban growth model prediction and analysis for the Changjiang Delta Region. c. Unsuitable urban growth area, baseline1: envrionmental suitability vs. scenario 3: ecological system concern (forest protection), plus development corridors, 2011.



Appendix 4. Scenario 3: ecological system concern (forest protection), plus development corridors, urban growth model prediction and analysis for the Changjiang Delta Region. c. Unsuitable urban growth area, baseline1: envrionmental suitability vs. scenario 3: ecological system concern (forest protection), plus development corridors, 2020.

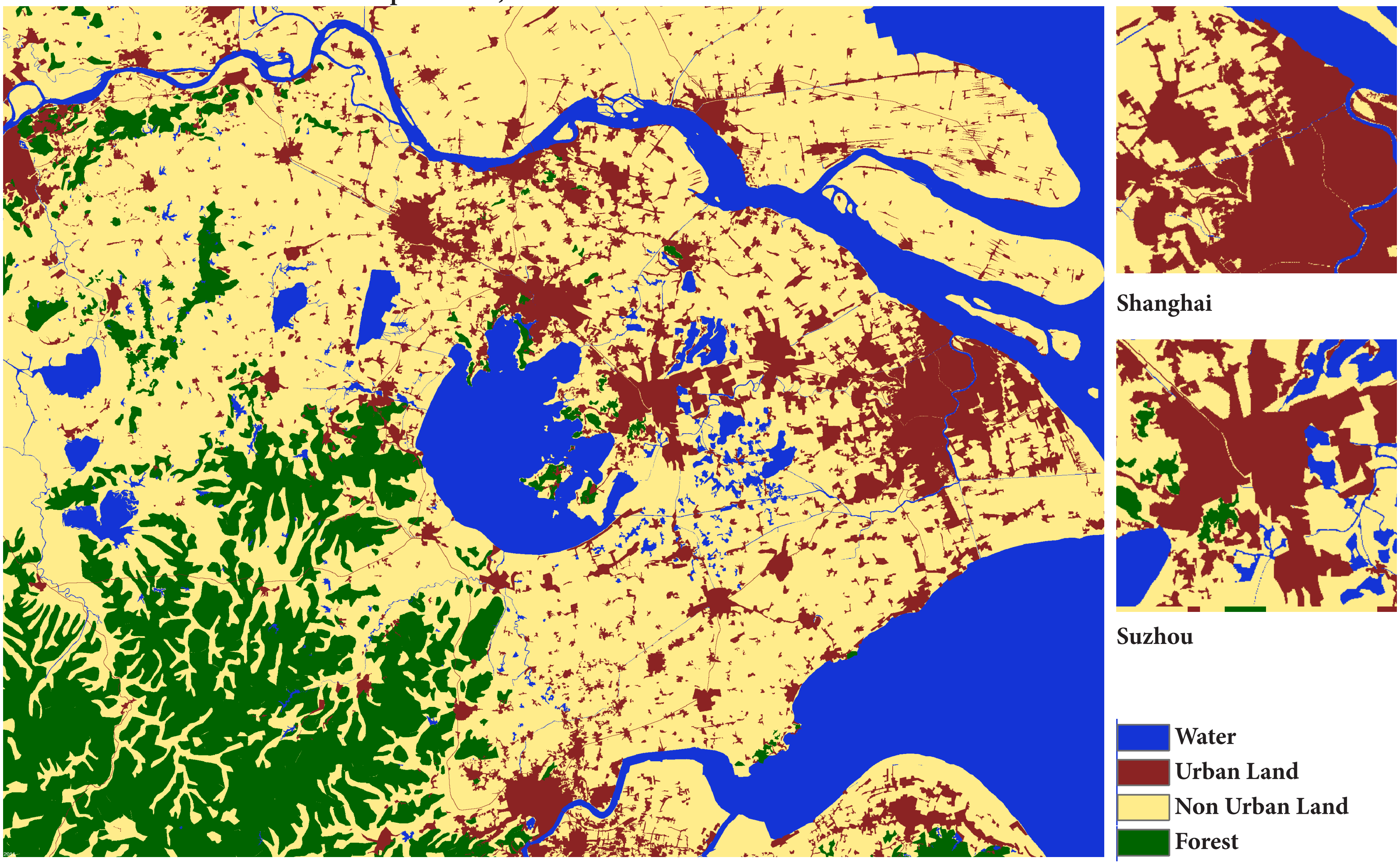


Appendix 4. Scenario 3: ecological system concern (forest protection), plus development corridors, urban growth model prediction and analysis for the Changjiang Delta Region. c. Unsuitable urban growth area, baseline1: envrionmental suitability vs. scenario 3: ecological system concern (forest protection), plus development corridors, 2030.



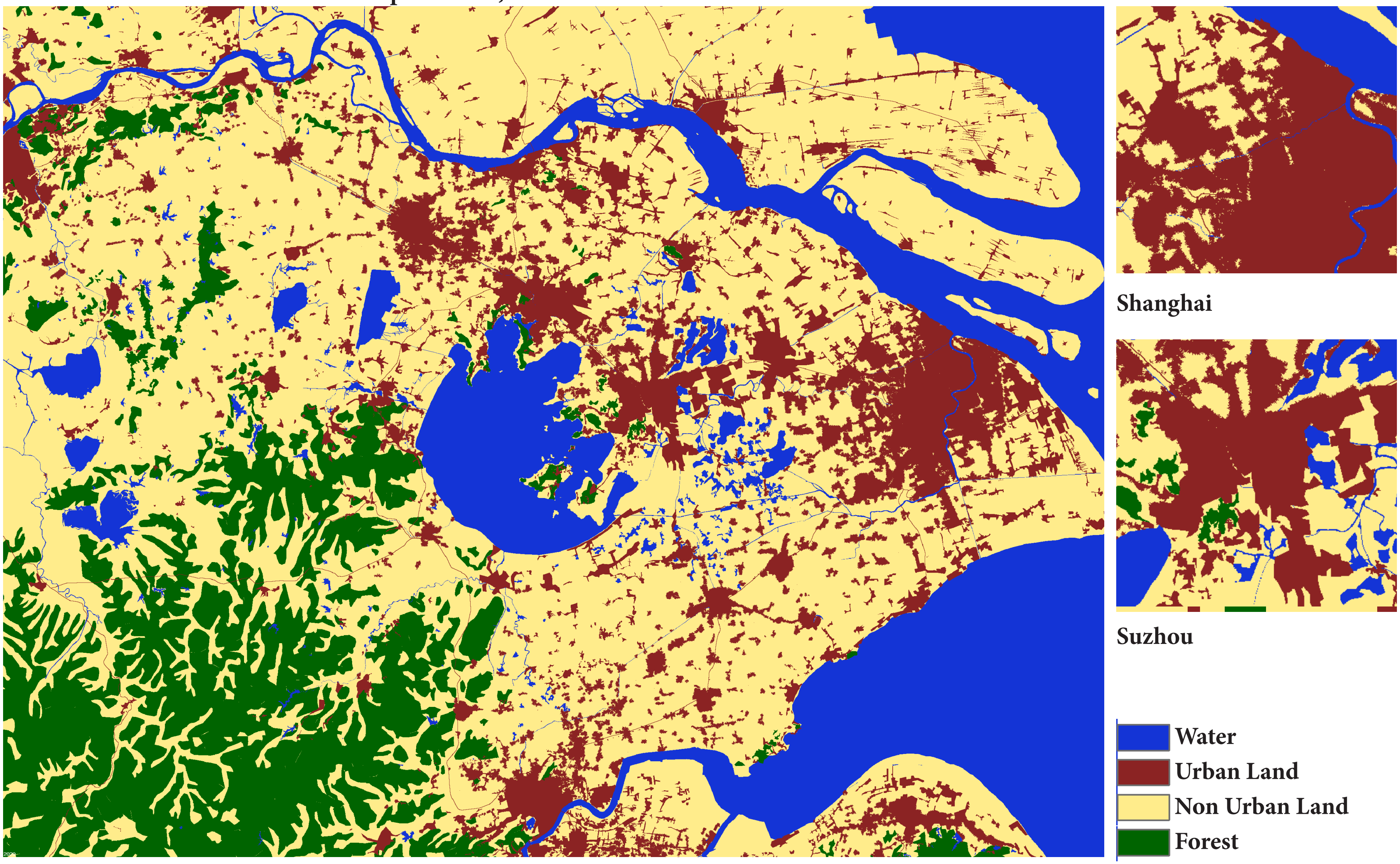
Appendix 5. Scenario 4: disaster prevention, plus development corridors, urban growth model prediction and analysis for the Changjiang Delta Region.

a. Scenario Cellular Automata model prediction, 2011.



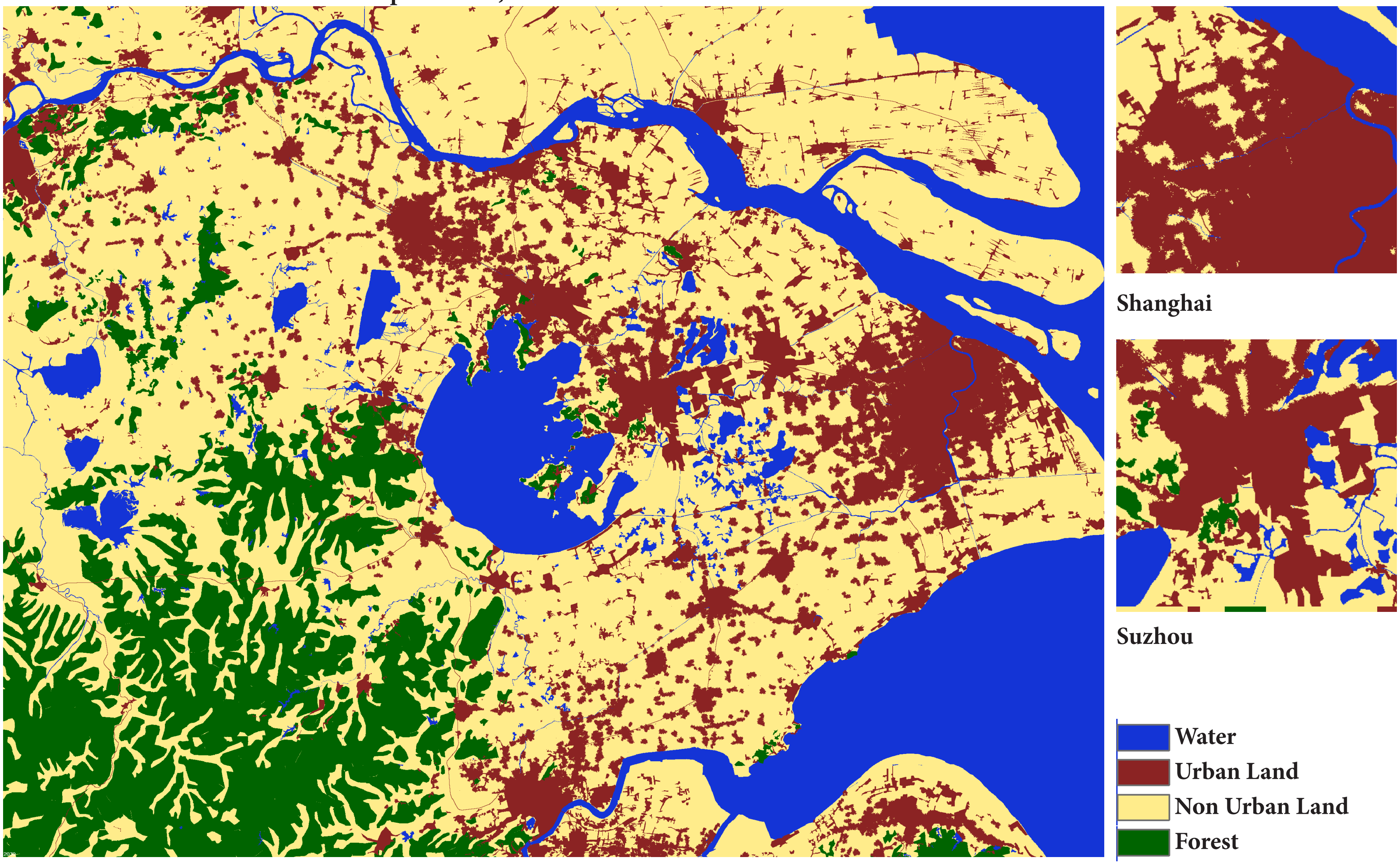
Appendix 5. Scenario 4: disaster prevention, plus development corridors, urban growth model prediction and analysis for the Changjiang Delta Region.

a. Scenario Cellular Automata model prediction, 2020.



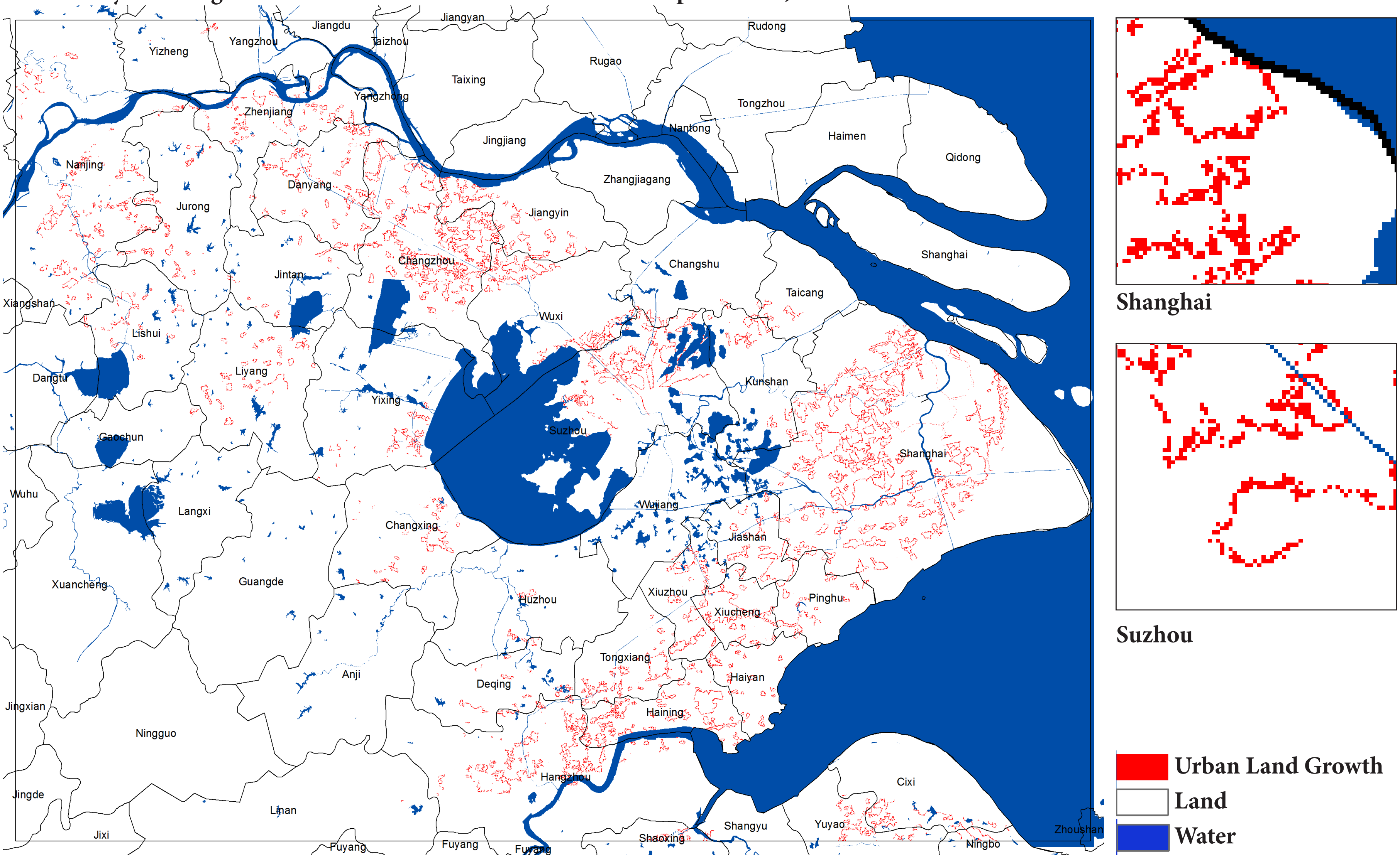
Appendix 5. Scenario 4: disaster prevention, plus development corridors, urban growth model prediction and analysis for the Changjiang Delta Region.

a. Scenario Cellular Automata model prediction, 2030.

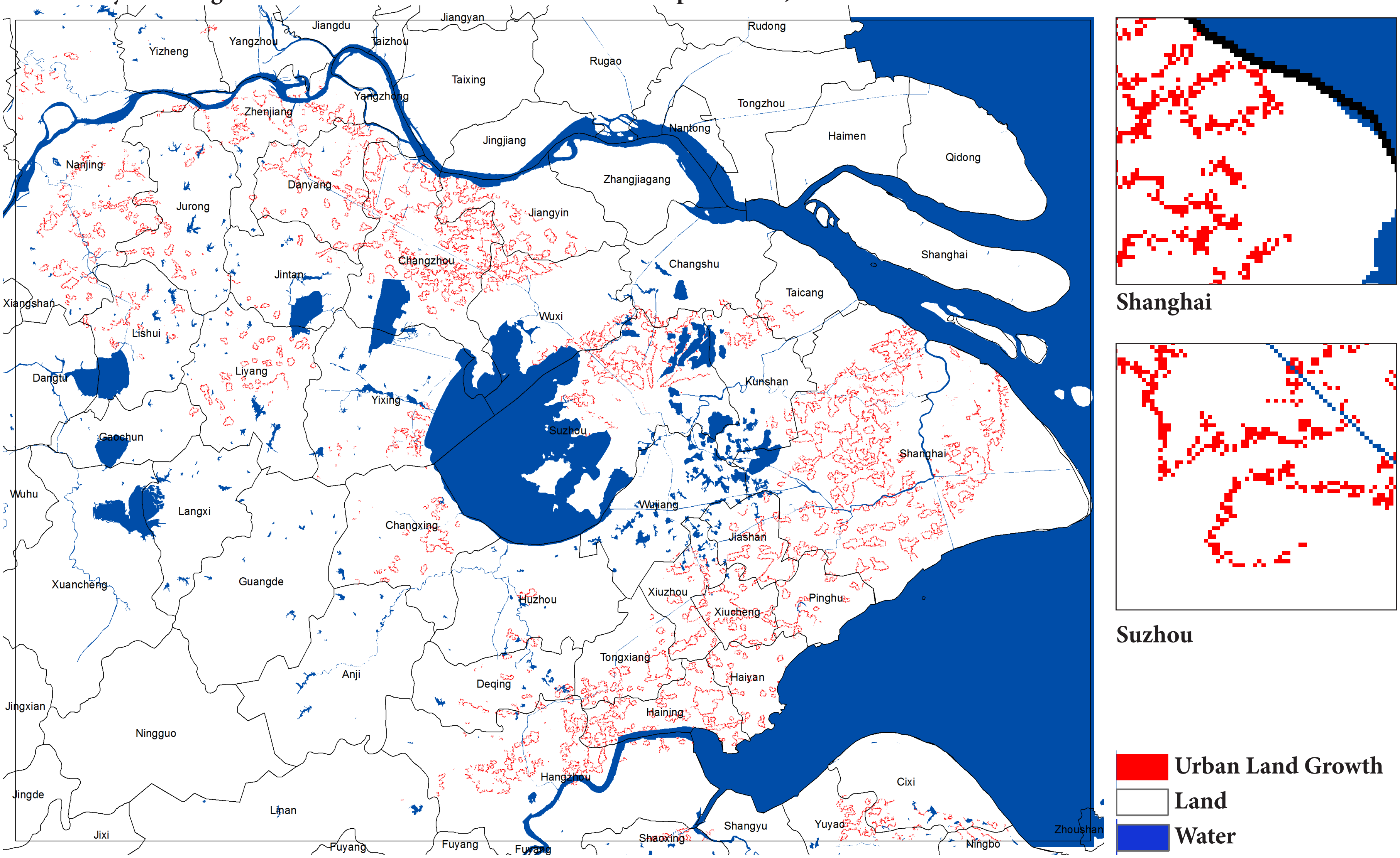


Appendix 5. Scenario 4: disaster prevention, plus development corridors, urban growth model prediction and analysis for the Changjiang Delta Region.

b. Interim year changes of the Scenario Cellular Automata model prediction, 2011-2020.

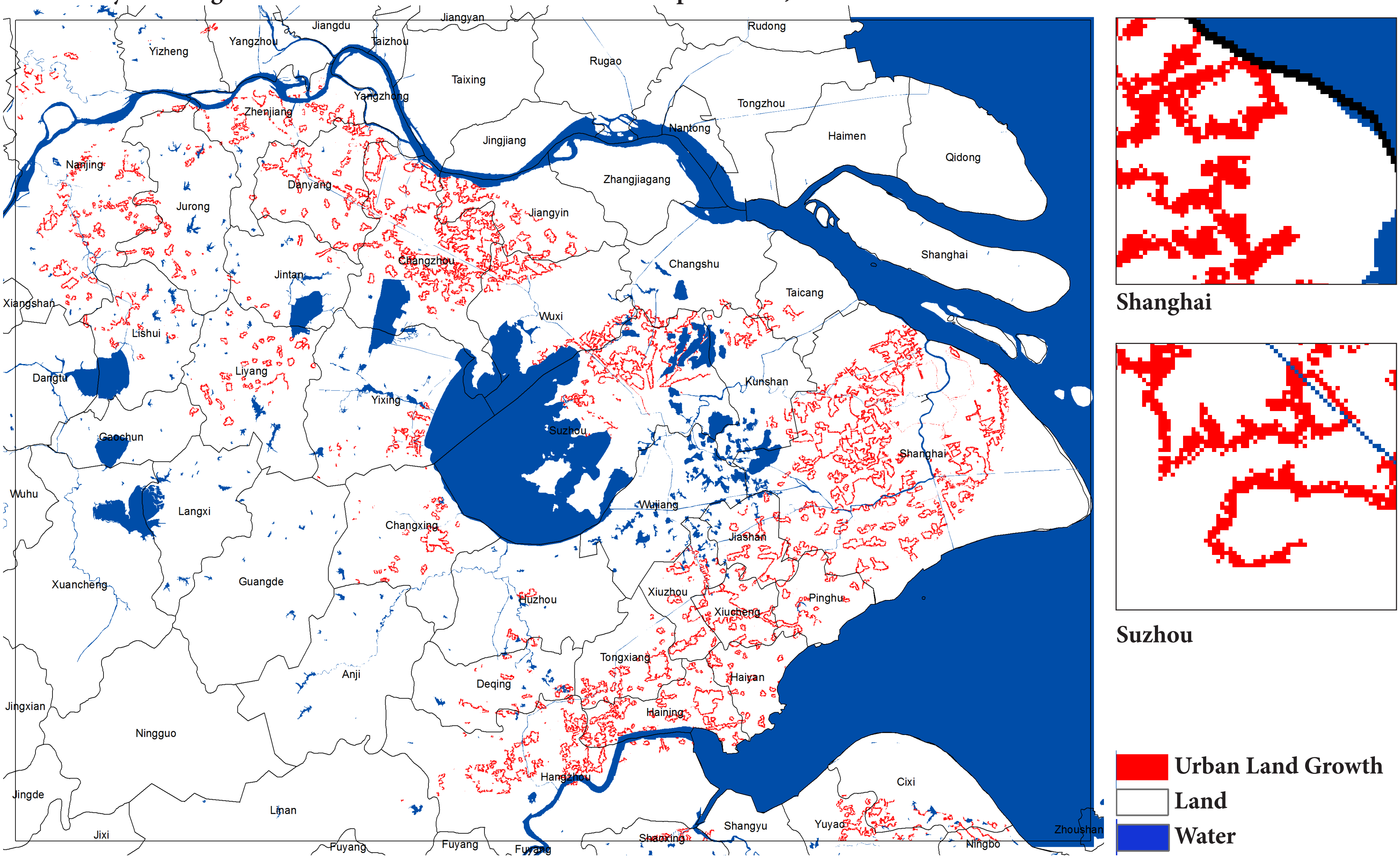


Appendix 5. Scenario 4: disaster prevention, plus development corridors, urban growth model prediction and analysis for the Changjiang Delta Region.
b. Interim year changes of the Scenario Cellular Automata model prediction, 2020-2030.

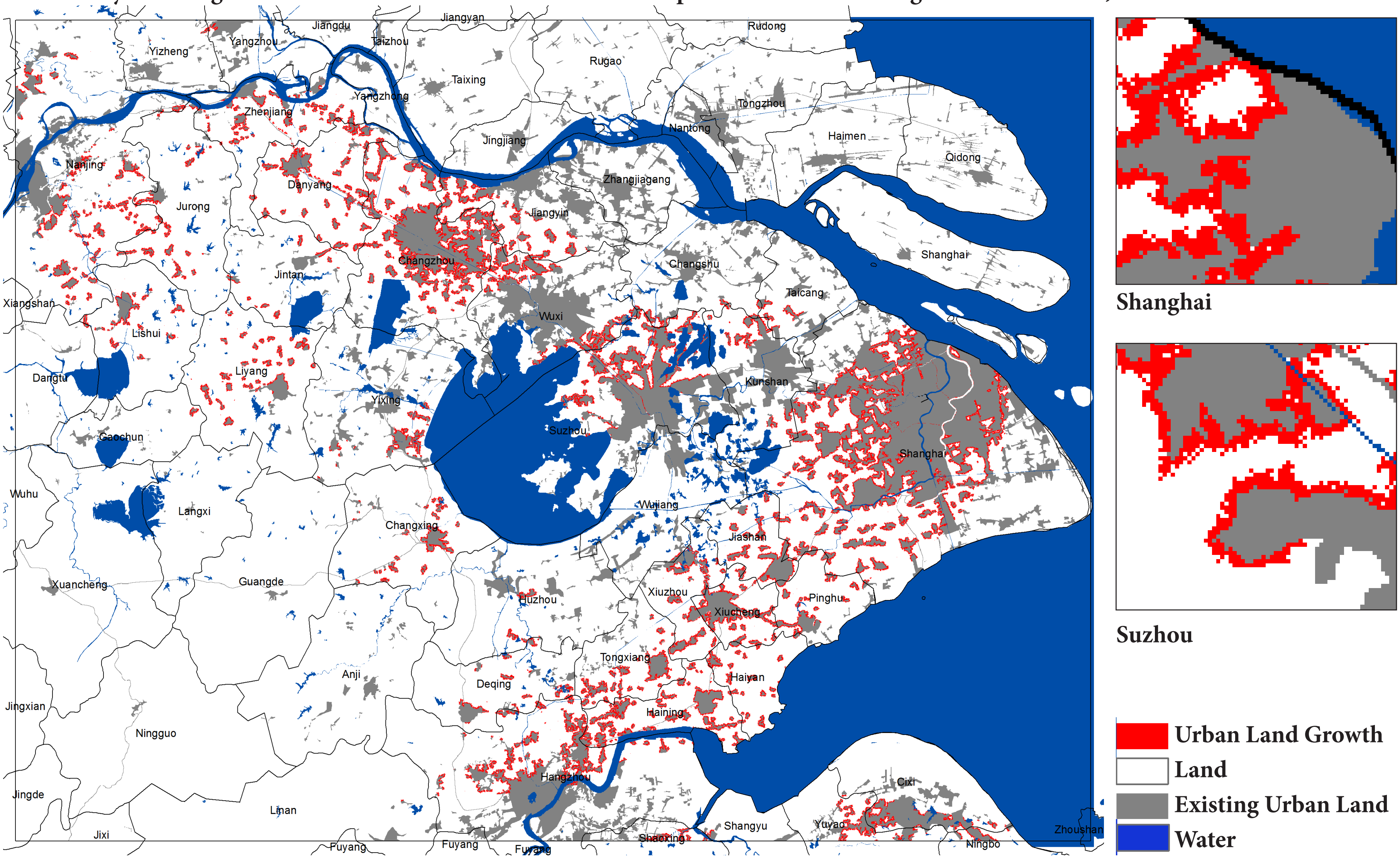


Appendix 5. Scenario 4: disaster prevention, plus development corridors, urban growth model prediction and analysis for the Changjiang Delta Region.

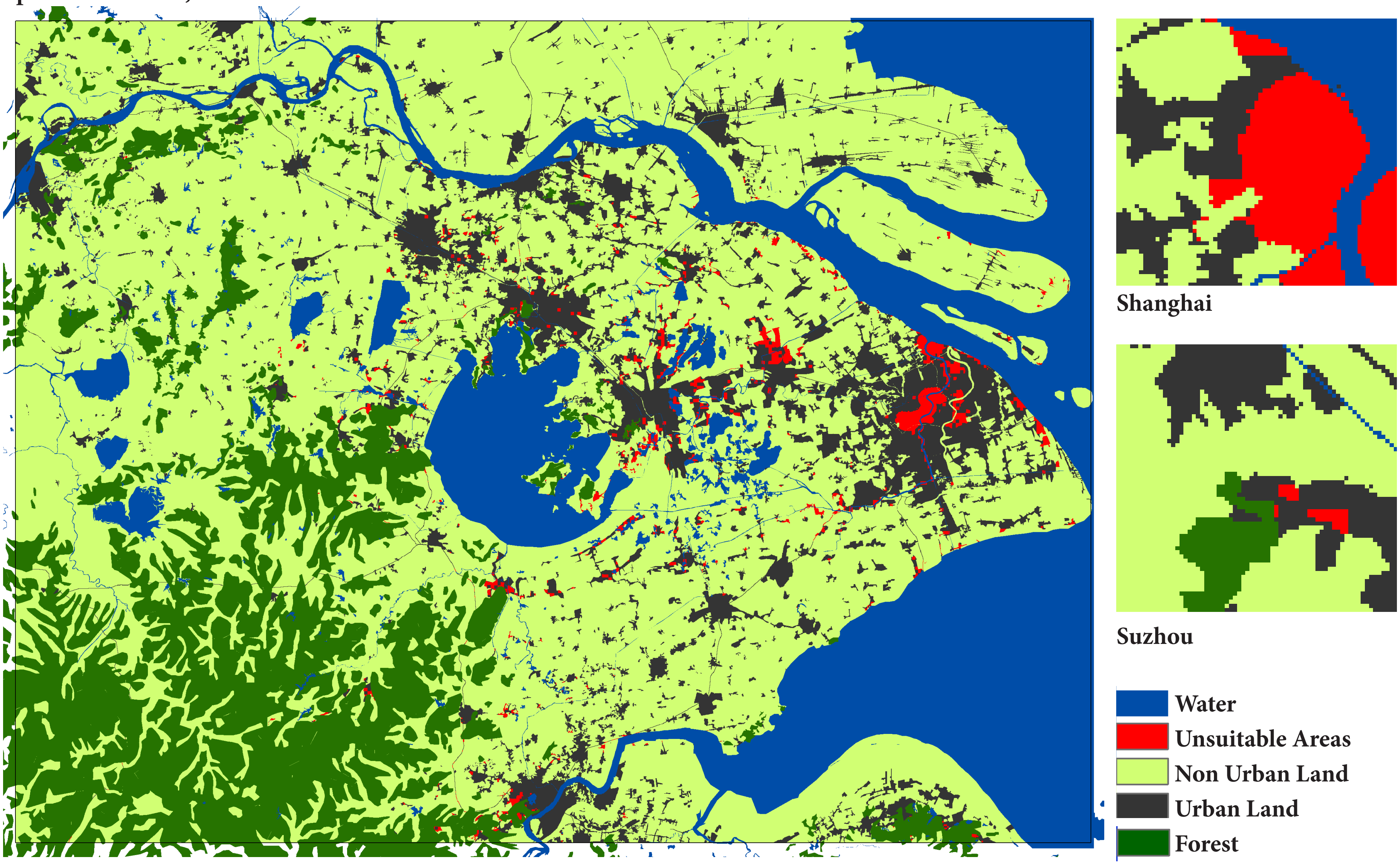
b. Interim year changes of the Scenario Cellular Automata model prediction, 2011-2030.



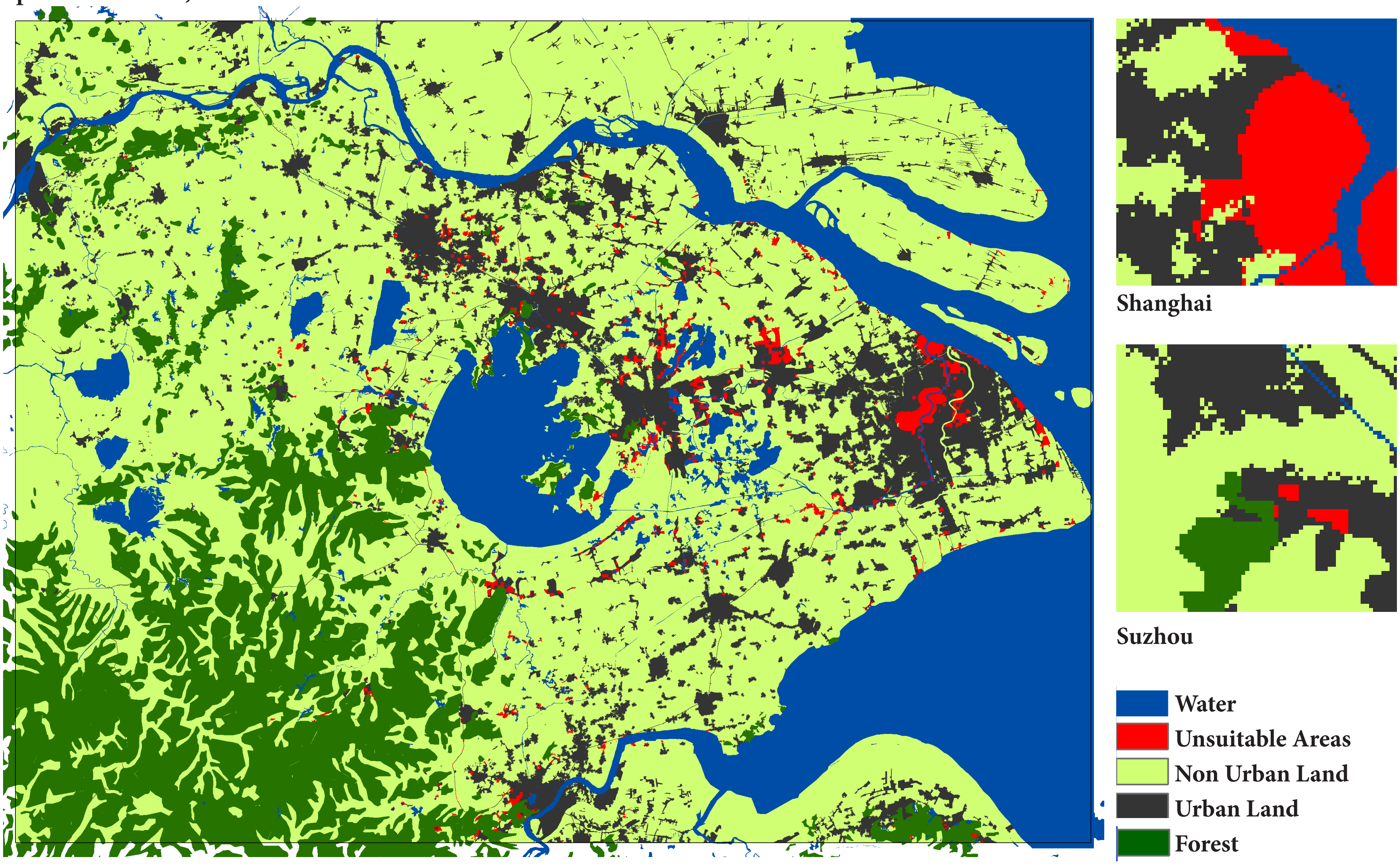
Appendix 5. Scenario 4: disaster prevention, plus development corridors, urban growth model prediction and analysis for the Changjiang Delta Region.
b. Interim year changes of the Scenario Cellular Automata model prediction with existing urban conditions, 2011-2030.



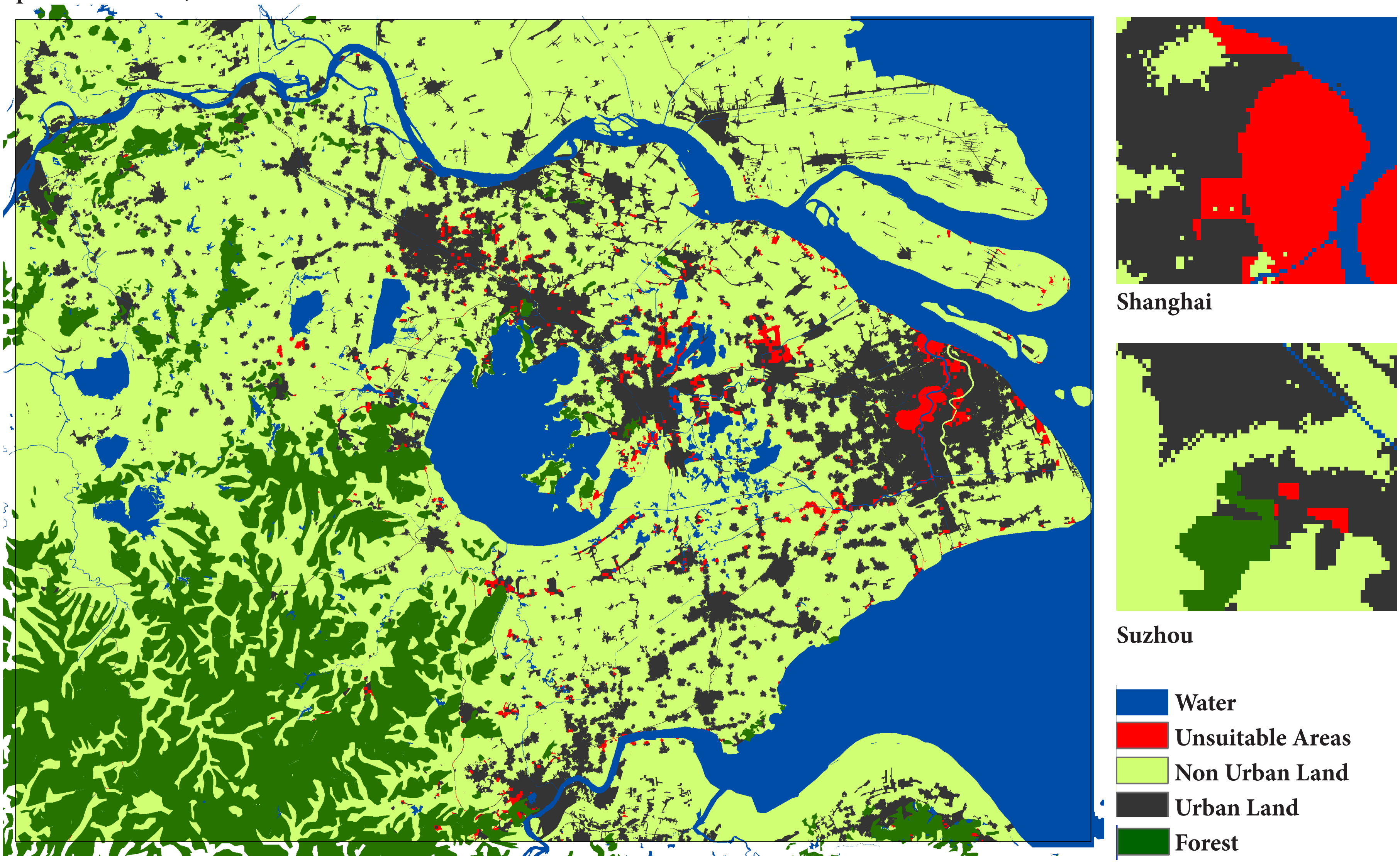
Appendix 5. Scenario 4: disaster prevention, plus development corridors, urban growth model prediction and analysis for the Changjiang Delta Region. c. Unsuitable urban growth area, baseline1: envrionmental suitability vs. scenario 4: disaster prevention, plus development corridors, 2011.



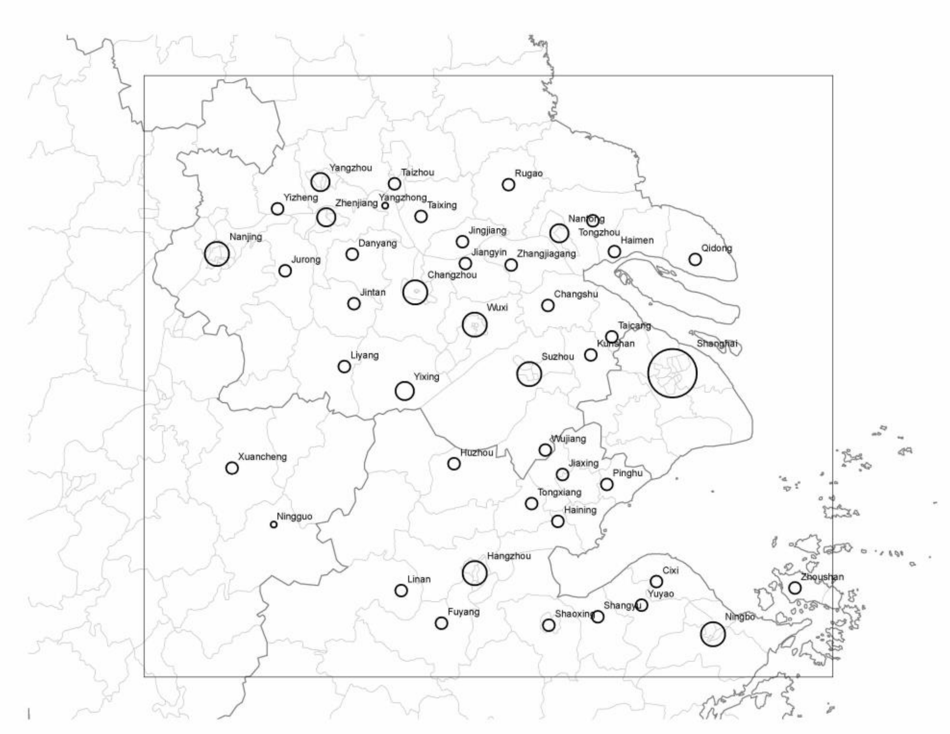
Appendix 5. Scenario 4: disaster prevention, plus development corridors, urban growth model prediction and analysis for the Changjiang Delta Region. c. Unsuitable urban growth area, baseline1: envrionmental suitability vs. scenario 4: disaster prevention, plus development corridors, 2020.



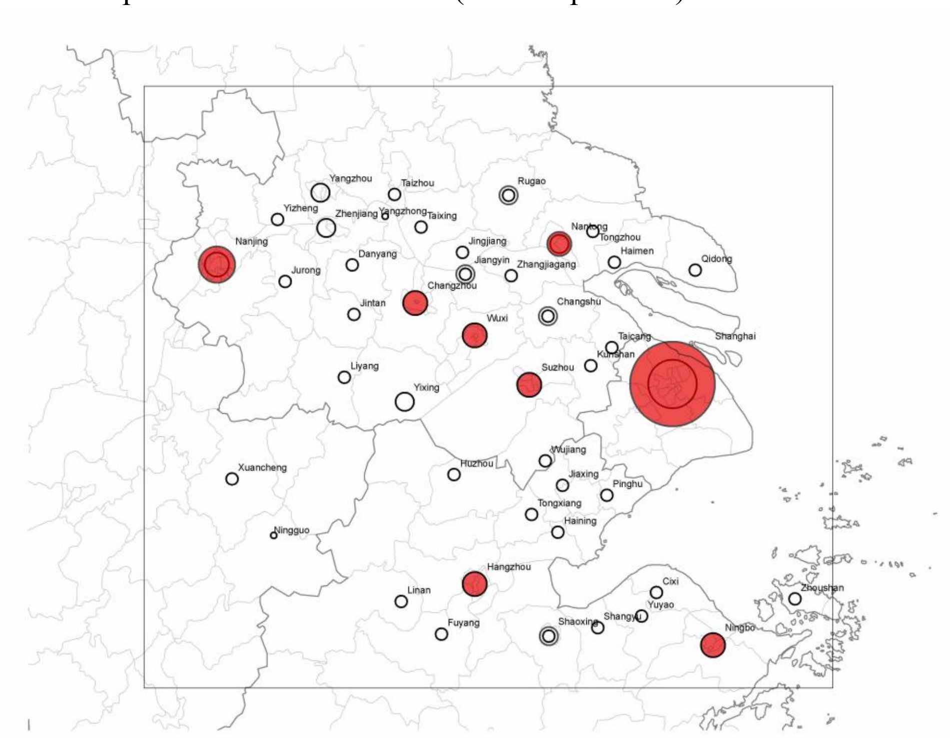
Appendix 5. Scenario 4: disaster prevention, plus development corridors, urban growth model prediction and analysis for the Changjiang Delta Region. c. Unsuitable urban growth area, baseline1: envrionmental suitability vs. scenario 4: disaster prevention, plus development corridors, 2030.



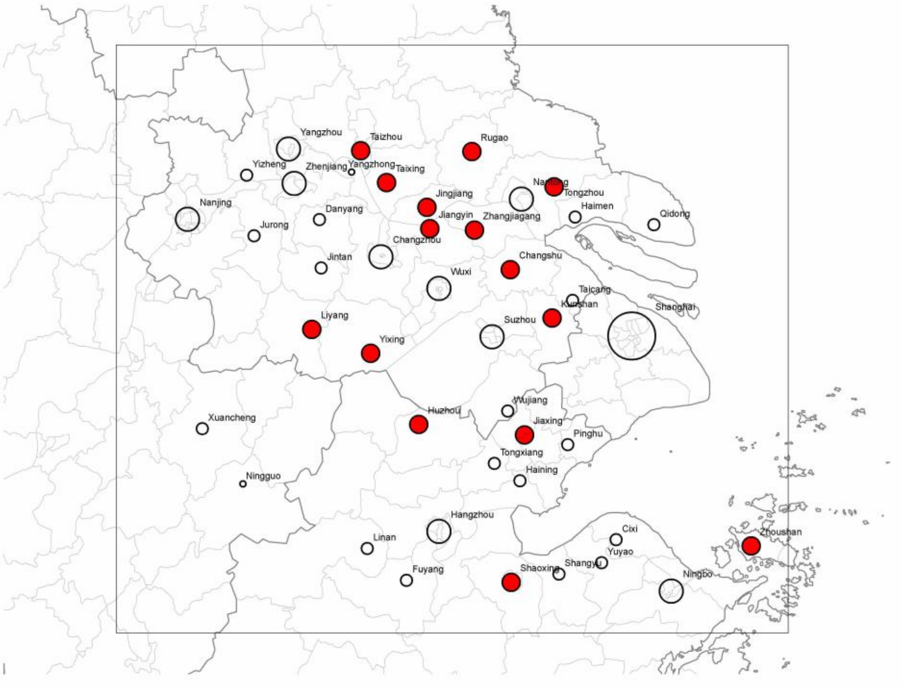
Appendix 6. A basic scenario involving modeling of current trends and other projected alternative circumstances describing Changjiang Delta regional network.



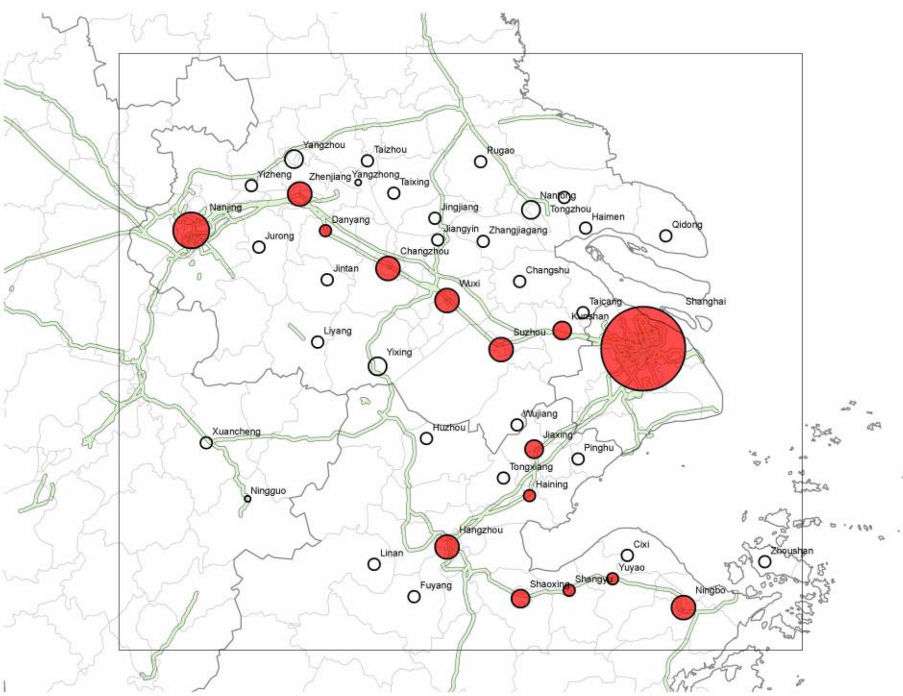
a. Development with no constrains (2010 Population)



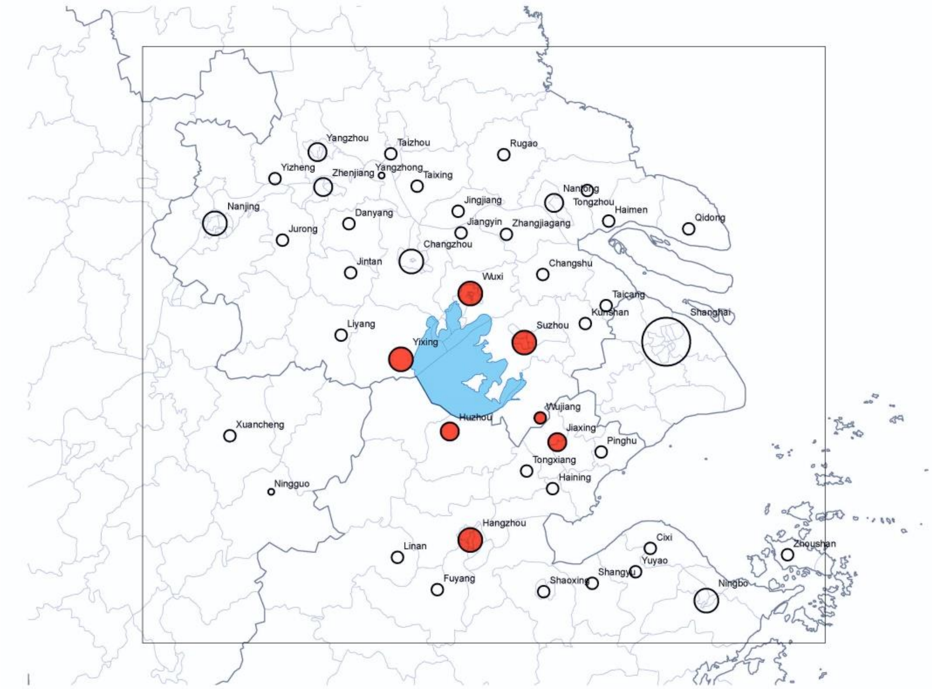
b. Big cities grow bigger, smaller cities merge or disappear



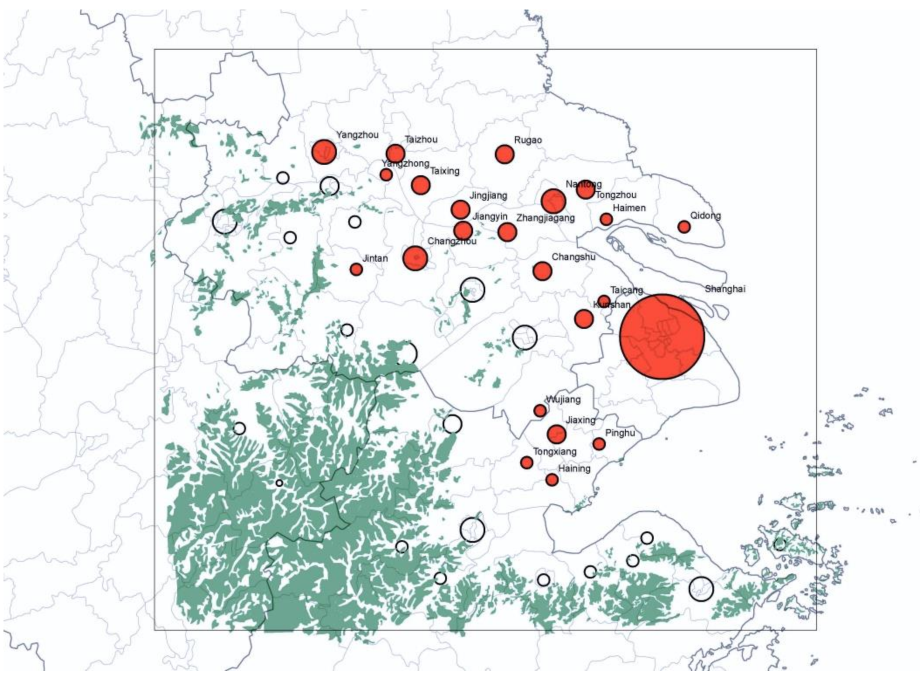
c. Small cities grow bigger, big cities growth is constrained



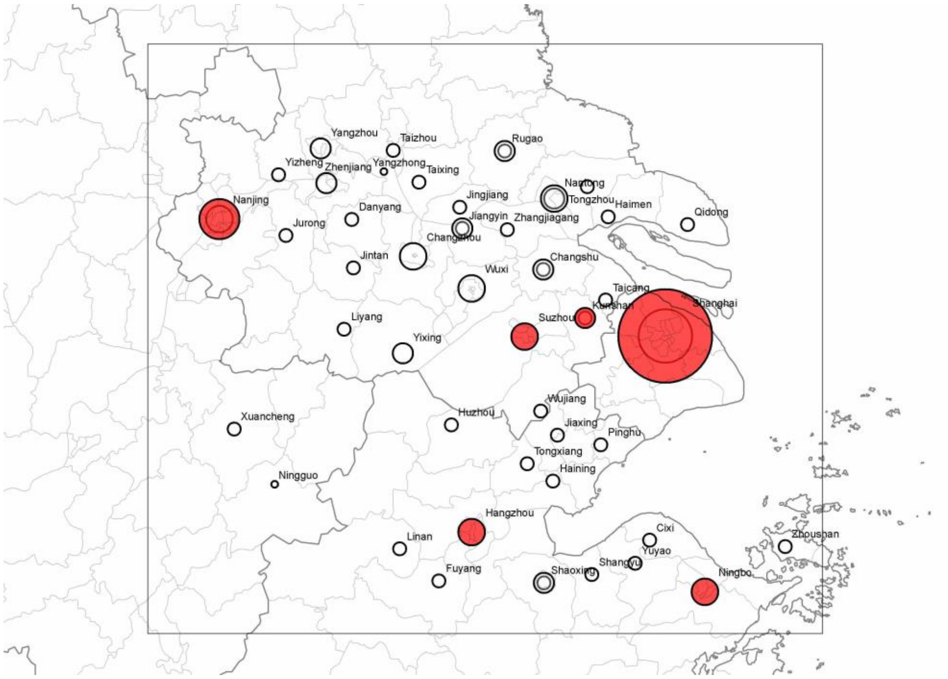
d. Development corridors



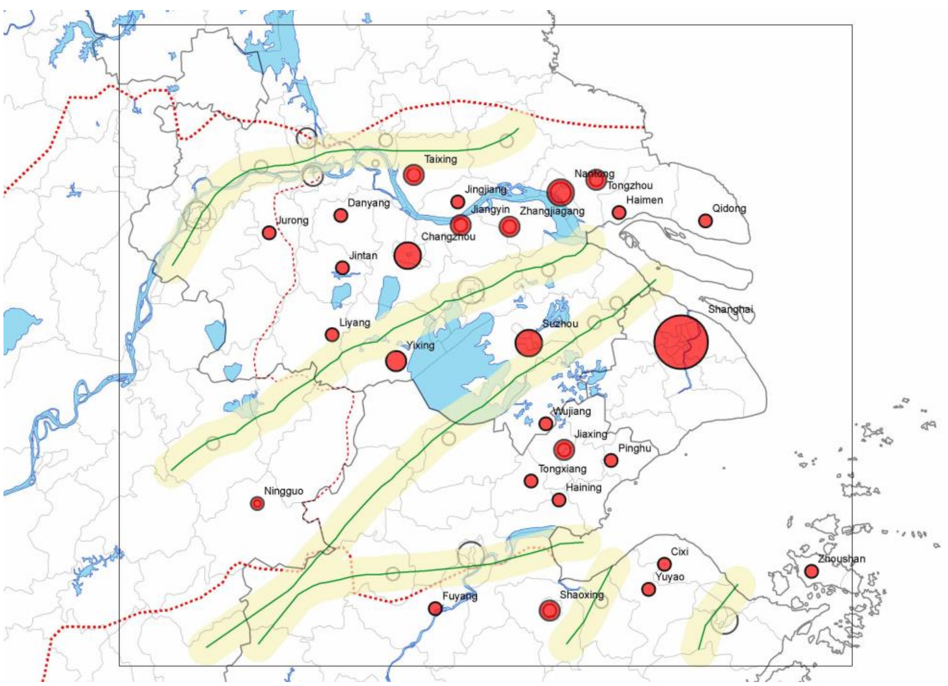
e. Life style attractions to places of high culture and environment amenity are emphasized



f. Environmental concerns play a determinate role



g. Uneven FDI distribution across the region takes place



h. Disaster prevention, flooding, and resiliency of cities become predictors